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(54) An auto-tuning controller.

(57) An auto-tuning controller comprising: a controller for controlling a controlled system; a reasoning rule memory for storing a reasoning rule to be used for reasoning an optimum c ntrol parameter of said controller; and an adjustment secti n for adjusting said optimum control parameter of said controller by a fuzzy reasoning with the use of said reasoning rule.

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An Auto-tuning Controller

FIELD OF THE INVENTION

The present invention relates to an auto-tuning controller provided with a function of automatically adjusting the control parameter in accordance with the characteristics of the controlled system used in such as a controller conducting a process control.

BACKGROUND ART

Conventionally, an auto-tuning controller such as shown in Figure 19 is adopted. This is one recited in an article by A.B. Corripio, P.M. Tompkins, "Industrial Application of a Self-Tuning Feedback Control Algorithm", ISA Transactions, vol. 20, No. 2, 1981, pp3 to 10. In Figure 19, the reference numeral 1 designates a reference value signal generator, the reference numeral 502 designates an auto-tuning controller, the reference numeral 3 designates a controlled system, the reference numeral 4 designates a PID controller, the reference numeral 5 designates a mathematical model operator, the reference numeral 6 designates an identifier, and the reference numeral 7 designates an adjustment operator.

The operation of this device will be described.

The auto-tuning controller 502 receives the reference value signal r(k) which is output from the

reference value signal generator 1 and the controlled variable y(k) which is output from the controlled system 3 as its inputs, and outputs a manipulated variable u(k) which is to be input to the controlled system 3. The values in parenthesis represent discrete timings at respective sampling invervals.

The operation inside the auto-tuning controller is as described below.

At first, an error e(k) between the reference value signal r(k) and the controlled variable y(k) is calculated.

$$e(k) = r(k) - y(k) \qquad \ldots(1)$$

The PID controller 4 receives the error e(k) as its input, and calculates the manipulated variable u(k) with the use of the control parameters which are previously established to output the same. The control parameters in the PID controller 4 are the gain K_C, integration time T_I, and differentiation time T_D, and the manipulated variable u(k) is calculated from these parameters as in the following.

$$u(k) = u(k-1) + Kc\ [\, e(k) - e(k-1) + \frac{T}{T_I} e(k) + \frac{T_D}{T} \{ e(k) - 2e(k-1) + e(k-2) \} \,] \qquad \ldots(2)$$

The manipulated variable u(k) becomes the input to the controlled system 3 as well as the inputs to the

mathematical model operator 5 and the identifier 6.

The mathematical model operator 5 calculates the output v(k) from the input manipulated variable u(k), for example, with the use of such as the mathematcial model of the following formula.

$$v(k) = a_1 \; v(k-1) + a_2 \; v(k-2) + b_1 \; u(k-m-1) + b_2 \; u(k-m-2) \quad \ldots(3)$$

Herein, m is an integer larger than or equal to 0, which means a dead time.

The identifier 6 obtains the coefficients a_1, a_2, b_1, and b_2 of the formula (3) such that the input-output relation of the controlled system 3 and that of the mathematical model operator 5 are equivalent to each other, that is, the outputs y(k) and v(k) of the both circuits are equal to each other. For this purpose, the identifier 6 receives the manipulated variable u(k), the controlled variable y(k), and the output of the mathematical model v(k) as its inputs.

For the description of the operation of the identifier 6, the following vectors x(k), z(k), and ϕ(k) are defined.

$$x^T(k-1) = [\, y(k-1),\; y(k-2),\; u(k-m-1),\; u(k-m-2) \,] \quad \cdots(4)$$

$$z^T(k-1) = [\, v(k-1),\; v(k-2),\; u(k-m-1),\; u(k-m-2) \,] \quad \cdots(5)$$

$$\phi(k) = [\, a_1,\; a_2,\; b_1,\; b_2 \,] \quad \cdots(6)$$

Herein, the suffix T at right shoulder of the vector represents a transport of the vector.

The identifier 6 executes the next algorithm.

$$G(k) = \{1 + z^T(k)P(k)x(k)\}^{-1} z^T(k)P(k) \quad \cdots (7)$$

$$\phi(k+1) = \phi(k) + \{y(k+1) - \phi(k)x(k)\} G(k) \cdots (8)$$

$$P(k+1) = P(k) - P(k)x(k)G(k) \quad \cdots (9)$$

The vector $\phi(k)$, that is, the coefficients a_1, a_2, b_1, and b_2 of the mathematical model formula (3) are obtained successively by this algorithm.

The vector $\phi(k)$ which is obtained in this way is output from the identifier 6, and is sent to the mathematical model operator 5 to be used for modifying the mathematical model, and is sent to the adjustment operator 7 to be used for obtaining the control parameters, that is, the gain K_C, integration time T_I, and differentiation time T_D. The adjustment operator 7 conducts the following operation in order to obtain these control parameters.

$$K_c = (a_1 + 2a_2)Q / b_1 \quad \cdots (10)$$

$$T_I = \frac{T}{\left[\dfrac{1}{a_1 + 2a_2} - 1 - \dfrac{T_D}{T}\right]} \quad \cdots (11)$$

$$T_D = \frac{T a_2 Q}{K_c b_1} \quad \cdots (12)$$

Herein, Q which appears in the formulae (10) and (12) are defined by the following formula.

$$Q = 1 - e^{-T/B} \quad \ldots(13)$$

Herein, B is an adjustment parameter, and in more detail, a desired time constant in a closed loop.

The gain K_C, integration time T_I, and differentiation time T_D obtained in this way are sent to the PID controller 4 to be again used for calculating the manipulated variable u(k) from the error e(k) with using the formula (2).

In this prior art auto-tuning controller with such a construction it is required to conduct the identification of the controlled system, and there are following problems in this identification.

(1) The calculation is very complicated.

(2) The quantity of the calculation amounts to a large volume.

(3) It takes a long time for the calculation to converge.

(4) It is impossible to deal with the non-linearity which is possessed by the controlled system.

(5) This controller is improper for the identification of the controlled system of the type other than that which is determined by

the mathematical model of the formula (3) because the type of the mathematical model is restricted to that of the formula (3) in this controller.

(6) There arises redundancy because the four coefficients a_1, a_2, b_1, and b_2 are identified in order to obtain the three control parameters K_P, T_I, and T_D.

These problems in the identification have been problems in the prior art auto-tuning controller as they are.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an auto-tuning controller capable of reasoning optimum control parameters of the controlled system from the error between the controlled variable and the test signal, the controlled variable, or the test signal with using the reasoning rules which are previously obtained from the experience rules and perceptions of human beings without conducting the identification of the controlled system.

A second object of the present invention is to provide such a type of auto-tuning controller including a position type fuzzy reasoner.

A third object of the present invention is to

provide such a type of auto-tuning controller including a position type fuzzy reasoner which utilizes a step response of a controlled system for obtaining the characteristics variable of the controlled system.

A fourth object of the present invention is to provide such a type of auto-tuning controller including a position type fuzzy reasoner which utilizes a pulse response of a controlled system for obtaining the characteristics variable of the controlled system.

A fifth object of the present invention is to provide such a type of auto-tuning controller including a velocity type fuzzy reasoner.

A sixth object of the present invention is to provide such a type of auto-tuning controller including a velocity type fuzzy reasoner which utilizes a pulse response of a controlled system for obtaining the characteristics variable of the controlled system.

Other objects and advantages of the present invention will become apparent from the detailed description given hereinafter; it should be understood, however, that the detailed description and specific embodiment are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

According to the present invention, there is provided an auto-tuning controller comprising: a controller for controlling a controlled system; a reasoning rule memory for storing a reasoning rule to be used for reasoning an optimum control parameter of said controller; and an adjustment section for adjusting said optimum control parameter of said controller by a fuzzy reasoning with the use of said reasoning rule.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram showing an auto-tuning controller as a first embodiment of the present invention;

Figure 2 is a flowchart describing the operation of the first embodiment;

Figure 3 is a diagram showing an example of evaluation by the membership function thereof;

Figure 4 is a diagram showing the mechanism of the fuzzy reasoning thereof;

Figure 5 is a block diagram showing an auto-tuning controller as a second embodiment of the present invention;

Figure 6 is a flowchart describing the operation of the second embodiment;

Figure 7 is a diagram showing an example of

evaluation by the membership function thereof;

Figure 8 is a diagram showing the mechanism of the fuzzy reasoning thereof;

Figure 9 is a block diagram showing an auto-tuning controller as a third embodiment of the present invention;

Figure 10 is a flowchart describing the operation of the third embodiment;

Figure 11 is a diagram showing an example of evaluation by the membership function thereof;

Figure 12 is a diagram showing the mechanism of the fuzzy reasoning thereof;

Figure 13 is a block diagram showing a fourth embodiment of the present invention;

Figure 14 is a flowchart describing the operation of the fourth embodiment;

Figure 15 is a diagram showing the mechanism of the fuzzy reasoning thereof;

Figure 16 is a block diagram showing an auto-tuning controller as a fifth embodiment of the present invention;

Figure 17 is a flowchart describing the operation of the fifth embodiment;

Figure 18 is a diagram showing the mechanism of the fuzzy reasoning thereof; and

Figure 19 is a block diagram showing a prior art auto-tuning controller.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In order to explain the present invention in detail, reference will be particularly made to Figure 1.

Figure 1 shows an auto-tuning controller as a first embodiment of the present invention. In Figure 1, the reference numeral 1 designates a reference value signal generator, which generates a reference value signal r(k). The reference numeral 2 designates an auto-tuning controller, and this auto-tuning controller receives the reference value signal r(K) and the controlled variable y(k) which is the output of the controlled system 3, and outputs the manipulated variable u(k). The reference numeral 3 designates a controlled system. This controlled system 3 receives the manipulated variable u(k) and outputs the controlled variable y(k). As described above, the controlled variable y(k) is feedbacked to the auto-tuning controller 2.

The internal construction of the auto-tuning controller 2 will be described.

The reference numeral 4 designates a controller, and in this embodiment a PID controller is used

therefor. This PID controller 4 receives the error between the reference value signal r(k) and the controlled variable y(k), and outputs the manipulated variable u(k) in accordance with the previously established control parameters, that is, the gain K_C, integration time T_I, and differentiation time T_D. The reference numeral 8 designates a characteristics variable extractor which receives such as the error e(k), the reference value signal r(k), and the manipulated variable y(k), and outputs the characteristics variable S_i ; i = 1, 2, ..., n representing the characteristics of the controlled system 3. The reference numeral 9 designates an reasoning rule memory which stores the reasoning rules R_j ; j = 1, 2, ..., m to be used for reasoning the optimum control parameters from the characteristics variables S_i. The reference numeral 10 designates a position type fuzzy reasoner which reasons and outputs the optimum control parameters, that is, the gain K_C, integration time T_I, and differentiation time T_D in accordance with the reasoning rule R_j with receiving the input characteristics variable S_i. The K_C, T_I, and T_D are given to the PID controller 4 to be again used for the calculation of the manipulated variable u(k). Thus, an adjustment section 11 for adjusting the

control parameters of the controller 4 by a fuzzy reasoning in accordance with the reasoning rule is constituted by the characteristics variable extractor 8 and the position type fuzzy reasoner 10.

The operation of this device will be described with reference to the flowchart of Figure 2.

At first, the value of K is set to 0 at step 111. Next, the control parameters are initiallized at step 121 as in the followings. That is, the gain K_C is initiallized at a relatively small value K_{CO}. The integration time T_I and differentiation time T_D are initiallized at infinity and 0, respectively, or at maximum and minimum, respectively. The PID controller 4 calculates the formula (2) with the use of the above-described initiallized parameters and controls the controlled system 3. Meanwhile, such as the error e(k), the reference value signal r(k), or the controlled variable y(k) are recorded.

When these data are gathered over n samples, the characteristics variable extractor 8 calculates the characteristics variable S_i ; i = 1, 2, ..., n from these data. The above-described characteristics variables are as described below.

$$S_1 = \text{(mean error)} = \frac{1}{N} \sum_{k=1}^{N} |\ e(k)\ | \qquad \ldots(14)$$

S_2 = (mean error change rate)

$$= \frac{1}{N-1} \sum_{k=2}^{N} | e(k) - e(k-1) | \qquad \ldots(15)$$

At step 181 the position type fuzzy reasoner 10 fuzzy reasons the optimum control parameters from the characteristics variable in accordance with the reasoning rules R_j ; j = 1, 2, ..., m stored at the reasoning rule memory 9, and outputs the same to the PID controller 4.

Thereafter, at steps 191 to 201 the PID controller 4 calculates the formula (2) with the use of the control parameters given described above and continues the control of the controlled system 3.

The reasoning rule R_j stored at the reasoning rule memory 9 and the operation of the position type fuzzy reasoner 10 will be described.

At first, the reasoning rules R_j are those produced by that the experience rules or perceptions which a person utilizes in conducting the adjustment of control parameters are made rules, and these are, for example, as in the following.

R_1 : "If the mean error S_1 is large and the mean error change rate S_2 is large, then set the gain K_C at an intermediate value."

R_2 : "If the mean error S_1 is large and the mean

error change rate S_2 is small, then set the gain K_C at a large value."

⋮

As described above, the reasoning rule R_j has a form of "If ∼ , then ∼ .". The portion "If ∼ ," is called as a former part proposition, and the portion "then ∼ ." is called as a latter part proposition.

When the latter part proposition has a form of representing a value itself such as "take ∼ as ∼" or "set ∼ to ∼" as in the above-described reasoning rules R_1 and R_2, this fuzzy reasoning is especially called as a position type fuzzy reasoning. To the contrary, when the latter part proposition has a form of representing a variation of a value such as "increase ∼ by ∼" or "lengthen ∼ by ∼", this fuzzy reasoning is called as a velocity type fuzzy reasoning.

In this first embodiment of the present invention, the position type fuzzy reasoner 10 which conducts the position type fuzzy reasoning is provided. The operation of this position type fuzzy reasoner 10 will be described as follows.

In the fuzzy reasoning, at first it is evaluated how much degree the present state satisfies with the condition of the former part proposition with the use of the membership function, and it is represented by a

value between 0 and 1.

Figure 3 shows an example of evaluation by the membership function. Herein, a proposition "the mean error S_1 is large" is adopted. It is assumed that the mean error calculated by the characteristics variable extractor 8 is that $S_1 = S_1{}^*$. Then, the degree to that the former part proposition comes into existence is evaluated as 0.75.

Figure 4 shows the mechanism of the fuzzy reasoning which is conducted by the position type fuzzy reasoner 10. In this fuzzy reasoning, the mean error S_1 and the mean error change rate S_2 are selected as the characteristics variables, and the above-described rules R_1 and R_2 are used as reasoning rules. Herein, only the adjustment of the gain is described, but the principle of the reasoning is also applied to the adjustments of the integration time and the differentiation time.

At first, the degrees to that the former part propositions of the fuzzy reasoning rules R1 and R2 come into existence are evaluated as described above. Herein, when the former part proposition comprises a plurality of terms and has a form of "If ~ and ~", the lowest one among the degrees to that the respective terms come into existence becomes the degree to that

the entirety of the former part proposition comes into existence. In the example of Figure 4, the actual values of the mean error S_1 and the mean error change rate S_2 are that $S_1 = S_1*$ and $S_2 = S_2*$. Then, the degree to that the proposition "If the mean error S_1 is large" of the rule R_1 comes into existence is 0.75, and the degree to that the proposition "If the mean error change rate S_2 is large" comes into existence is 0.2. Accordingly, the degree to that the entirety of the former part proposition comes into existence is 0.2.

The latter part proposition is also represented by the membership function as shown in Figure 4. Because the degree to that the former part proposition of the rule R_1 is 0.2, the membership function of the latter part proposition is reduced to 0.2 times as that of the latter part proposition itself.

Finally, the reduced membership functions of the latter part propositions of the respective rules R_1 and R_2 are put one upon another, and the center of gravity of them is obtained. The value of the gain K_C at this center of gravity is adopted as the optimum gain.

Similarly as above, the optimum integration time and the optimum differentiation time are reasoned.

Figure 5 shows a second embodiment of the present invention.

In Figure 5 the same reference numerals designate the same elements as those shown in Figure 1. The reference numeral 108 designates a controlled system input switch for selecting one from the manipulated variable u(k) and the test signal T(k) as the input to be input to the controlled system 3. The reference numeral 109 designates a test signal generator for generating a test signal T(k). The characteristics variable extractor 8 receives the test signal T(k) and the output y(k) of the controlled system 3 which is a response against the test signal T(k), and outputs a characteristics variable S_i : i = 1, 2, ..., n representing the characteristics of the controlled system 3. The reference numeral 102 designates an auto-tuning controller of this second embodiment, and the adjustment section 11 for adjusting the control parameters is constituted by the characteristics variable extractor 8, the position type fuzzy reasoner 10, and the test signal generator 109.

The operation of this second embodiment will be described with reference to the flowchart of Figure 6.

The operation of this embodiment is separated into a former part comprising the steps 132 to 162 of the automatic adjustment mode for conducting the automatic adjustment of the control parameters and a latter part

comprising the steps 172 to 182 of the control mode for conducting the control of the controlled system 3 in accordance with the control parameters adjusted at the former part steps.

At first, the controlled system input switch 108 is switched to the side a at step 132.

Next, the test signal generator 109 generates a test signal T(k) which is a step signal in this case at step 142. The test signal T(k) becomes an input to the controlled system 3 through the controlled system input switch 108.

At step 152 the characteristics variable extractor 8 receives the test signal T(k) and the output y(k) of the controlled system 3 which is a response against the test signal, and calculates the characteristics variable S_i representing the control property of the controlled system 3 and outputs the same.

At step 162, the position type fuzzy reasoner 10 fuzzy-reasons the optimum control parameters from the characteristics variable S_i in accordance with the reasoning rule R_j stored at the reasoning rule memory 9, and gives the same to the PID controller 4.

Thus, the former part operation, that is, the automatic adjustment of the control parameters is concluded.

The latter part operation comprises the steps 172 and 182 of the control mode for conducting the control of the controlled system 3 after the adjustment of the control parameters.

At step 172, the controlled system input switch 108 is switched to the side b. Thus, the input to the controlled system 3 is switched from the test signal T(k) to the manipulated variable u(k) which is the output of the PID controller 4.

At step 182 the PID controller 4 calculates the formula (2) with the use of given control parameters and controls the controlled system 3.

Figure 7 shows an example of fuzzy reasoning by which the characteristics variable S_i is extracted from the test signal T(k) and the output y(k) of the controlled system 3 which is a response against the test signal T(k). Herein, a step signal is used as the test signal T(k). As the characteristics variable S_i the followings S_1 and S_2 are, for example, selected with the use of the response error ε(k) of the controlled system 3 against the test signal T(k) which is also shown below.

$$\varepsilon(k) = T(k) - y(k) \qquad \ldots(16)$$

$$S_1 = \frac{1}{N} \sum_{k=1}^{N} |\varepsilon(k)| \qquad \ldots(17)$$

$$S_2 = -\frac{\varepsilon_{peak}}{\varepsilon(0)} \qquad \ldots(18)$$

⋮

Herein, N is a positive integer which is previously established, and ε_{peak} is the maximum peak of the $\varepsilon(k)$ at the negative side.

In this second embodiment of the present invention, the position type fuzzy reasoner 8 which conducts the position type fuzzy reasoning is provided. The operation thereof will be described as follows.

Figure 8 shows the mechanism of the position type fuzzy reasoning. Herein, the S_1 and S_2 of the formulae (17) and (18) are selected as characteristics variables, and R_1 and R_2 which are described below are used as reasoning rules.

R_1 : "If S_1 is large and S_2 is also large, then set the K_C at an intermediate value."

R_2 : "If S_1 is large and S_2 is not large, then set the K_C at a large value."

⋮

At first it is evaluated to how much degree the present state satisfies with the condition of the former part proposition of the fuzzy reasoning rules R_1 and R_2. Herein, the actual values of S_1 and S_2 are assumed to be that $S_1 = S_1^*$ and $S_2 = S_2^*$. These values

are evaluated by the, membership functions. For example, with respect to the reasoning rule R_1, if S_1 is large and S_2 is also large as shown by the left side two graphs at the upper stage of Figure 8 it is evaluated that the present state satisfies them to the degree of 0.75 and 0.2, respectively. Then, it is judged that the former part proposition of the rule R_1 is satisfied to the degree of 0.2 from the lower value among them.

The latter part proposition "set the K_C at an intermediate value" is also represented by a membership function, and this membership function is weighted by the degree to that the former part proposition comes into existence.

Finally, the weighted membership functions of the latter part propositions of the respective rules R_1 and R_2 are put one upon another and the center of gravity of them is obtained. The value of the gain K_C of this center of gravity is adopted as the optimum gain.

Similar operations as those described above are conducted also for the integration time and differentiation time.

In this way, the position type fuzzy reasoner 10 reasons the optimum control parameters.

Figure 9 shows a third embodiment of the present

invention. In Figure 9 the same reference numerals designates the same elements as those shown in Figures 1 and 5. In this embodiment, an error switch 208 is provided at a stage prior to the PID controller 4 so as to select one as error input e(k) which is to be input to the PID controller 4 from the error between the reference value signal r(k) and the output y(k) of the controlled system 3 and the error between the test signal T(k) from the test signal generator 209 and the output y(k). Furthermore, the auto-tuning controller 202 of this third embodiment receives the reference value signal r(k) and the controlled variable y(k) which is the output of the controlled system 3 as its inputs, and outputs manipulated variable u(k). The output y(k) of the controlled system 3 is feedbacked to the auto-tuning controller 202. In this embodiment the adjustment section 11 for adjusting the control parameters are constituted by the characteristics variable extractor 8, the position type fuzzy reasoner 10, and the test signal generator 209.

The operation of this third embodiment will be described with reference to the flowchart of Figure 10.

In this flowchart, the former part steps 133 to 183 constitute an automatic adjustment mode for conducting the automatic adjustment of the control

parameters, and the latter part steps 193 and 203 constitute a control mode for conducting the control of the controlled system in accordance with the control parameters adjusted at the former part steps.

At first, at step 133 the control parameters are initiallized at appropriate values. For example, the gain K_C is set at a relatively small value K_{C0}, the integration time T_I and differentiation time T_D are set at infinity and 0, or at maximum and minimum, respectively.

At steps 143 to 163 the PID controller 4 receives the error e(k) between the test signal T(k) which is a pulse signal in this case and the controlled variable y(k),

$$e(k) = T(k) - y(k) \qquad ...(19)$$

as its inputs. That is, the PID controller 4 controls the controlled system 3 in accordance with the test signal T(k) with the use of the initiallized control parameters.

At step 173 the characteristics variable extractor 8 receives the error e(k) of the formula (17), and T(k), y(k) as its inputs, and calculates the characteristics variable S_i representing the control property of the controlled system 3 to output the same.

At step 183, the position type fuzzy reasoner 10

reasons the optimum control parameters from the characteristics variable S_i in accordance with the reasoning rule R_j stored at the reasoning rule memory 9, and gives the same to the PID controller 4.

Having done the above-described steps, the operation of the automatic adjustment of control parameters, that is, the adjustment mode is concluded.

At step 193 the auto-tuning controller enters the control mode for controlling the controlled system 3 in accordance with the reference value signal r(k), and at step 203 the main operation of the control mode is conducted.

The characteristics variable S_i which is output from the characteristics variable extractor 8, the reasoning rule R_j stored at the reasoning rule memory 9, and the position type fuzzy reasoning conducted by the position type fuzzy reasoner 10 will be described. Herein, the automatic adjustment of the gain is only described for simplification.

Figure 11 shows an example of the characteristics variable S_i. It is assumed that a pulse signal shown in the graph at the upper stage of Figure 11 is used as the test signal T(k). In this case the error e(k) between the test signal and the controlled variable according to the formula (19) becomes as shown in the

graph at the lower stage of Figure 11. From the characteristics of the waveform of the error e(k) the characteristics variables S_i are obtained, for example, as follows.

$$S_1 = -\frac{1}{2}\left(\frac{e_{p2}}{e_{p1}} + \frac{e_{p3}}{e_{p2}}\right) \quad \ldots(20)$$

$$S_2 = \frac{1}{N}\sum_{k=1}^{N} |e(k)| \quad \ldots(21)$$

Herein, e_{p1}, e_{p2}, and e_{p3} designate the negative, positive, and negative peak value which appear after the test signal, respectively, and the e(1), ..., e(N) designate errors from after the test signal up to a predetermined time thereafter.

In this third embodiment of the present invention, the position type fuzzy reasoner 8 which conducts the position type fuzzy reasoning is provided. The operation thereof will be described as follows.

Figure 12 shows the mechanism of this position type fuzzy reasoning. Herein, the S_1 and S_2 of the above-described formulae (20) and (21) are selected as characteristics variables, and R_1 and R_2 which are described below are used as reasoning rules.

R_1 : "If S_1 is large and S_2 is small, then set the K_C at a small value."

R_2 : "If S_1 is small and S_2 is also small, then set the K_C at an intermediate value."

⋮

At first, it is evaluated to how much degree the present state satisfies with the condition of the former part proposition of the fuzzy reasoning rule. Herein, it is assumed that the values of S_1 and S_2 are actually to be such that $S_1 = S_1*$ and $S2 = S_2*$, respectively. These values are evaluated by the membership functions. For example, with respect to the reasoning rule R_1, the propositions "S_1 is large" and "S_2 is small" are evaluated to be satisfied with to the degree of 0.75 and 0.5, respectively, as shown in the left side two graphs at the upper stage of Figure 12. Then, it is assumed that the entirety of the former part proposition of the rule R_1 is satisfied with to the degree of 0.5 from the lower value among them.

Next, the membership function of the latter part proposition "then set K_C at a small value" is weighted by the degree of 0.5 to that the former part proposition is satisfied with. This manner is shown in the third from the left graph at the upper stage of Figure 12.

Finally, the weighted membership functions of the latter part propositions of the respective rules R_1 and

R_2 are put one upon another so as to calculate the center of gravity. The value of the gain K_C at the center of gravity is adopted as the optimum gain.

The integration time and differentiation time are also reasoned as similarly above, and the optimum control parameters are reasoned in this way by the position type fuzzy reasoner 10.

Figure 13 shows a fourth embodiment of the present invention. In Figure 13 the same reference numerals designate the same or corresponding elements as those shown in Figures 1, 5, and 9.

The internal construction of the adjustment section 11 for adjusting the control parameters of this embodiment will be described. The reference character 8 designates a characteristics variable extractor which has the same or similar function as that of the above-described embodiments. The reference numeral 311 designates a velocity type fuzzy reasoner which receives the characteristics variable S_i as its input and reasons how much the control parameters, that is, the gain K_C, integration time T_I, and differentiation time T_D should be adjusted from their present values in order to optimize the same, and outputs the adjustment variable ΔK_C, ΔT_I, and ΔT_D. The reference numeral 312 designates an integrator which receives ΔK_C, ΔT_I,

or ΔT_D as its input, and integrates the same to output it as an actual parameter. The control parameters output from the integrator 312 are given to the controller 4 to be used for calculating the manipulated variable u(k) from the error e(k). The reference numeral 302 designates an auto-tuning controller of this fourth embodiment.

The operation of this fourth embodiment will be described with reference to the flowchart of Figure 14.

In an auto-tuning controller using a velocity type fuzzy reasoner the automatic adjustment can be conducted at an arbitrary time in conducting the control. In this place an example in which the automatic adjustment is always conducted during the control operation is shown.

At first, the value of K is set to 0 at step 134. Next, the control parameters are initiallized at step 144. The values are set at sufficiently safety values in view of the stability rather than in view of the response and the preciseness.

Until it is judged that the control system is to be stopped, the auto-tuning controller of this embodiment repeats the operation of the steps 164 to 224.

At step 174 the PID controller 4 calculates the

formula (2) with the use of the present control parameters and controls the controlled system 3.

Accompanying with this, such as the error e(k - N), the manipulated variable u(k - N), and the controlled variable y(k - N) at the timing before N pieces of timings are erased, and new respective data e(k), u(k), and y(k) are recorded.

At step 194 it is judged as to whether the above-described data e(·), u(·), and y(·) are collected over N samples is not. Until the collection of the data is completed the step returns to prior the step 15.

At step 204 the characteristics variable extractor 8 calculates the characteristics variable S_i : i = 1, 2, ..., n from the over N samples collected data e(k - N + 1), ..., e(k), r(k - N + 1), ..., r(k), y(k - N - 1), ..., y(k). As the characteristics variables S_i the mean error S_1 and the mean error change rate S_2 which are represented by the formulae (14) and (15) are used.

At step 214 the velocity type fuzzy reasoner 11 receives the input characteristics variable S_i, and reasons how much the control parameters should be adjusted from the present values in order to optimize the control parameters in accordance with the reasoning rule R_j : j = 1, 2, ..., m stored at the reasoning rule

memory 8, and outputs the values, that is, the adjustment variable of the gain ΔK_C, the adjustment variable of the integration time ΔT_I, and the adjustment variable of the differentiation time ΔT_D.

At step 224 the integrators 312 integrate the input adjustment variables ΔK_C, ΔT_I, and ΔT_D, respectively, and output the actual control parameters K_C, T_I, and T_D to the PID controller 4.

The auto-tuning controller 302 controls the controlled system 3 with automatically adjusting the control parameters by repeating the above-described operations.

In this fourth embodiment of the present invention, the velocity type fuzzy reasoner 311 which conducts the velocity type fuzzy reasoning is provided. The operation thereof will be described as follows.

In the fuzzy reasoning it is evaluated to how much degree the present state satisfies with the condition of the former part proposition with the use of the membership function, and it is represented by a value between 0 and 1 as already shown in Figure 3.

Figure 15 shows the mechanism of reasoning conducted by the velocity type fuzzy reasoner 11. Herein, the mean error S_1 and the mean error change rate S_2 are selected as characteristics variables, and

R_1 and R_2 which are described below and shown in Figure 15 are used as reasoning rules.

R_1 : "If S_1 is small and S_2 is also small, then keep the K_C at the present value."

R_2 : "If S_1 is small and S_2 is large, then set the K_C at a small value."

.
.
.

In this place only the adjustment of the gain is described for simplification.

At first, the degrees to that the former part propositions of the fuzzy reasoning rules R_1 and R_2 come into existence are evaluated as described above. In the example of Figure 15 the proposition "If S_1 is small" of the rule R_1 comes into existence to the degree of 0.5, and the proposition "S_2 is also small" of the rule R_1 comes into existence to the degree of 0.2. It is judged that the entirety of the former part proposition of the rule R_1 comes into existence to the degree of 0.2 from the lower one among the two degrees.

The latter part proposition is also represented by the membership function. This membership function is weighted by the degree to that the former part proposition comes into existence. In the rule R_1 the latter part proposition is weighted to 0.2 times as that.

Finally, the weighted membership functions of the latter part propositions of the respective rules are put one upon another, and the center of gravity of them is calculated. The gain K_C at this center of gravity is adopted as the optimum gain adjustment variable ΔK_C.

Similarly as above the optimum integration time adjustment variable ΔT_I and the optimum differentiation time adjustment variable ΔT_D are reasoned.

The velocity type fuzzy reasoner 311 reasons the optimum adjustment variables of the control parameters as described above, and these values are given to the controller 4 as actual control parameters through the integrators 312.

Figure 16 shows a fifth embodiment of the present invention. In Figure 16 the same reference numerals designate the same elements as those shown in Figures 1, 5, 9, and 13. In this fifth embodiment an error switch 408 is provided at a stage prior to the PID controller 4 so as to select one as error input e(k) which is to be input to the PID controller 4 from the error between the reference value signal r(k) and the output y(k) of the controlled system 3 and the error between the test signal t(k) from the test signal

generator 409 and the output y(k). Furthermore, the auto-tuning controller 402 of this fifth embodiment receives the reference value signal r(k) and the controlled variable y(k) which is the output of the controlled system 3 as its inputs, and outputs manipulated variable u(k). The output y(k) of the controlled system 3 is feedbacked to the auto-tuning controller 402. In this embodiment the adjustment section for adjusting the control parameters is constituted by the characteristics variable extractor 8, the velocity type fuzzy reasoner 412, and the test signal generator 409.

The operation of this fifth embodiment will be described with reference to the flowchart of Figure 17.

The operation of this fifth embodiment is separated into the former part steps 145 to 205 of the automatic adjustment mode for conducting the automatic adjustment of the control parameters and the latter part steps 215 and 225 of the control mode for conducting the usual control in accordance with the control parameters adjusted at the above-described former part steps.

At first, at step 145 the error switch 8 is switched to the side a so as to enter the adjustment mode.

At steps 155 to 175 the PID controller 4 receives the error between the test signal T(k) and the controlled variable y(k) as its input,

$$e(k) = T(k) - y(k) \qquad ...(14)$$

and controls the controlled system 3. Meanwhile, the characteristics variable extractor 10 receives such as e(k) as its input, and calculates and outputs the characteristics variable S_i.

At step 185 it is judged whether the control property of the control system at present is a satisfactory one or not from the characteristics variable S_i.

When the control property at present is not a satisfactory one, the step proceeds to the steps 195 and 205, and the velocity type fuzzy reasoner 12 reasons how much the control parameters should be adjusted in order to make the control property a satisfactory one. Then, the integrator 413 adds the adjustment variable to the present value of the control parameter and gives the result to the controller 4.

Thereafter, the step again returns to prior to the step 155 and the above-described operation is repeated.

On the other hand, when the control property at present is judged to be a satisfactory one at step 185 the step proceeds to the steps 215 to 225.

At step 215 the mode is switched from the adjustment mode to the control mode. At step 225 the device is in a usual control mode and the controller conducts the control of the controlled system 3 in accordance with the reference value signal r(k).

The characteristics variable S_i which is output from the characteristics variable extractor 10, the reasoning rule R_j stored at the reasoning rule memory 11, and the velocity type fuzzy reasoning conducted by the velocity type fuzzy reasoner 12 will be described. Herein, only the adjustment of the gain will be described for simplification.

Figure 18 shows the mechanism of the velocity type fuzzy reasoning. Herein, as the characteristics variable S_i the S_1 and S_2 ... represented by the formulae (20) and (21) and shown in figure 11 are used. That is, a pulse response of the controlled system 3 is utilized similarly as in the third embodiment. R_1 and R_2 which are described below are used as the reasoning rules.

R_1 : "If S_1 is large and S_2 is small, then set the gain K_C at a little smaller value."

R_2 : "If S_1 is small and S_2 is also small, then keep the gain K_C at the present value."

⋮

At first, it is evaluated to how much degree the present state satisfies with the condition of the former part proposition of the fuzzy reasoning rule. Herein, it is assumed that the values of S_1 and S_2 are actually such that $S_1 = S_1*$ and $S_2 = S_2*$. These values are evaluated by the membership functions. For example, with respect to the reasoning rule R_1, the propositions "If S_1 is large" and "If S_2 is small" are evaluated to be satisfied with to the degree of 0.75 and 0.5, respectively, as shown in the left side two graphs at the upper stage of Figure 18. It is judged that the entirety of the former part proposition of the rule R_1 is satisfied with to the degree of 0.5 from the lower value among them.

Next, the membership function of the latter part proposition "then set K_C at a little small value" is weighted by the degree to that the former part proposition comes into existence. This manner is shown in the third from the left graph at the upper stage of Figure 18.

The above-described operations are conducted with respect to the respective rule R_j, and finally the weighted membership functions of the latter part propositions of the respective rules are put one upon another. Thereafter, the center of gravity of them is

calculated, and this calculated center of gravity is adopted as the optimum gain adjustment variable ΔK_C.

The reasonings are also conducted for the integration time and the differentiation time similarly as above, and the velocity type fuzzy reasoner 12 outputs the respective optimum adjustment variables ΔT_I and ΔT_D.

The optimum control parameter adjustment variables ΔK_C, ΔT_I, and ΔT_D are given to the controller 4 through the integrators 413 as actual control parameters, that is, K_C, T_I, and T_D.

In the above illustrated embodiments auto-tuning controllers which automatically adjust the gain, the integration time, and the differentiation time with using a PID controller, but the present invention can be also applied to the other type of auto-tuning controller. For example, the present invention can be applied to an auto-tuning controller which includes a controller which, including an ON, OFF, and unsensitive zone, automatically adjusts the width of the unsensitive zone. The present invention can be also applied to an auto-tuning controller which includes an optimum control controller which, based on the modern ages control theory, automatically adjusts the parameters of the evaluation function.

As is evident from the foregoing description, according to the present invention, the control parameters of the controller are fuzzy reasoned from the characteristics variables of the waveforms such as the input error or the controlled system response in accordance with the reasoning rules which are obtained from the experience rules and perceptions of human beings and previously stored, whereby the automatic adjustments of the control parameters can be conducted by simple operations of membership functions without conducting the identification which unfavourably rescricts the type of the controlled system and which is also a complicated one. This enables of conducting an automatic adjustment at a light operation load and at a short time, and of conducting an automatic adjustment against a wide range of controlled system.

WHAT IS CLAIMED IS:

1. An auto-tuning controller comprising:

a controller for controlling a controlled system;

an reasoning rule memory for storing a reasoning rule to be used for reasoning an optimum control parameter of said controller; and

an adjustment section for adjusting said optimum control parameter of said controller by a fuzzy reasoning with the use of said reasoning rule.

2. An auto-tuning controller as defined in claim 1, wherein said adjustment section comprises a characteristics variable extractor which receives a reference value signal output from a reference value signal generator, a controlled variable which is output from said controlled system, or an error between said reference value signal and said controlled variable, and outputs at least a characteristics variable representing the state of the controlled system, and a fuzzy reasoner which adjusts said control parameter in accordance with said reasoning rule from said characteristics variable.

3. An auto-tuning controller as defined in Claim

1, wherein said reasoning rule of velocity type fuzzy reasoning has a form comprising at least a former part proposition concerning a said characteristics variable the degree of coming into existence of which is represented by a predetermined membership function and a latter part proposition including an instruction concerning the adjustment of said control parameter.

4. An auto-tuning controller comprising:

a controller which receives an error between a reference value signal which is output from a reference value signal generator and a controlled variable which is output from a controlled system, and outputs an operation variable which is to be input to said controlled system;

a characteristics variable extractor which receives said error, said reference value signal, or said controlled variable, and outputs at least a characteristics variable representing the state of the controlled system;

a reasoning rule memory for storing a reasoning rule to be used for reasoning an optimum control parameter of said controller; and

a position type fuzzy reasoner which reasons an optimum control parameter in accordance with said reasoning rule from said characteristics variable and outputs said optimum control parameter to said controller.

5. An auto-tuning controller as defined in Claim 4, wherein said reasoning rule of position type fuzzy reasoning has a form comprising at least a former part proposition concerning a said characteristics variable the degree of coming into existence of which is represented by a predetermined membership function and a latter part proposition including an instruction concerning the adjustment of said control parameter.

6. An auto-tuning controller comprising:

a controller which receives an error between a reference value signal which is output from a reference value signal generator and a controlled variable which is output from a controlled system, and outputs an operation variable which is to be input to said controlled system;

a switch for selecting one from said operation quantity and a test signal as an input to said controlled system;

a test signal generator for generating a test

signal;

a characteristics variable extractor which receives said test signal and the output of said controlled system, and outputs at least a characteristics variable representing the characteristics of said controlled system;

a reasoning rule memory for storing a reasoning rule to be used for reasoning an optimum control parameter of said controller; and

a position type fuzzy reasoner which reasons an optimum control parameter in accordance with said reasoning rule from said characteristics variable and outputs said optimum control parameter to said controller.

7. An auto-tuning controller as defined in Claim 6, wherein said test signal is a step signal.

8. An auto-tuning controller as defined in Claim 6, wherein said reasoning rule of position type fuzzy reasoning has a form comprising at least a former part proposition concerning a said characteristics variable the degree of coming into existence of which is represented by a predetermined membership function and a latter part proposition including an instruction concerning the adjustment of said control parameter.

9. An auto-tuning controller comprising:

a controller which receives an error and outputs a manipulated variable as an input to a controlled system;

a switch for selecting one as said error from an error between the controlled variable which is output from said controlled system and a test signal and an error between a reference value signal which is output from a reference value signal generator and said controlled variable;

a characteristics variable extractor which receives the error between said controlled variable and said test signal, said controlled variable, or said test signal, and outputs a characteristics variable representing the characteristics of said controlled system;

a reasoning rule memory for storing a reasoning rule to be used for reasoning an optimum control parameter of said controller; and

a position type fuzzy reasoner which reasons an optimum control parameter in accordance with said reasoning rule from said characteristics

variable and outputs said optimum control parameter to said controller.

10. An auto-tuning controller as defined in Claim 9, wherein said test signal is a pulse signal.

11. An auto-tuning controller as defined in Claim 9, wherein said reasoning rule of position type fuzzy reasoning has a form comprising at least a former part proposition concerning a said characteristics variable the degree of coming into existence of which is represented by a predetermined membership function and a latter part proposition including an instruction concerning the adjustment of said control parameter.

12. An auto-tuning controller comprising:

a controller which receives an error between a reference value signal which is output from a reference value signal generator and a controlled variable which is output from a controlled system, and outputs an operation variable which is to be input to said controlled system;

a characteristics variable extractor which receives said error, said reference value signal, or said controlled variable, and outputs at least a characteristics variable representing the state of the controlled

system;

a reasoning rule memory for storing a reasoning rule to be used for reasoning an optimum control parameter of said controller;

a velocity type fuzzy reasoner which fuzzy-reasons the adjustment variable of the control parameter; and

an integrator which integrates the output of said velocity type fuzzy reasoner and outputs the result to said controller.

13. An auto-tuning controller comprising:

a controller which receives an error and outputs a manipulated variable as an input to a controlled system;

a switch for selecting as said error one from an error between the controlled variable which is output from said controlled system and a test signal and an error between a reference value signal which is output from a reference value signal generator and said controlled variable;

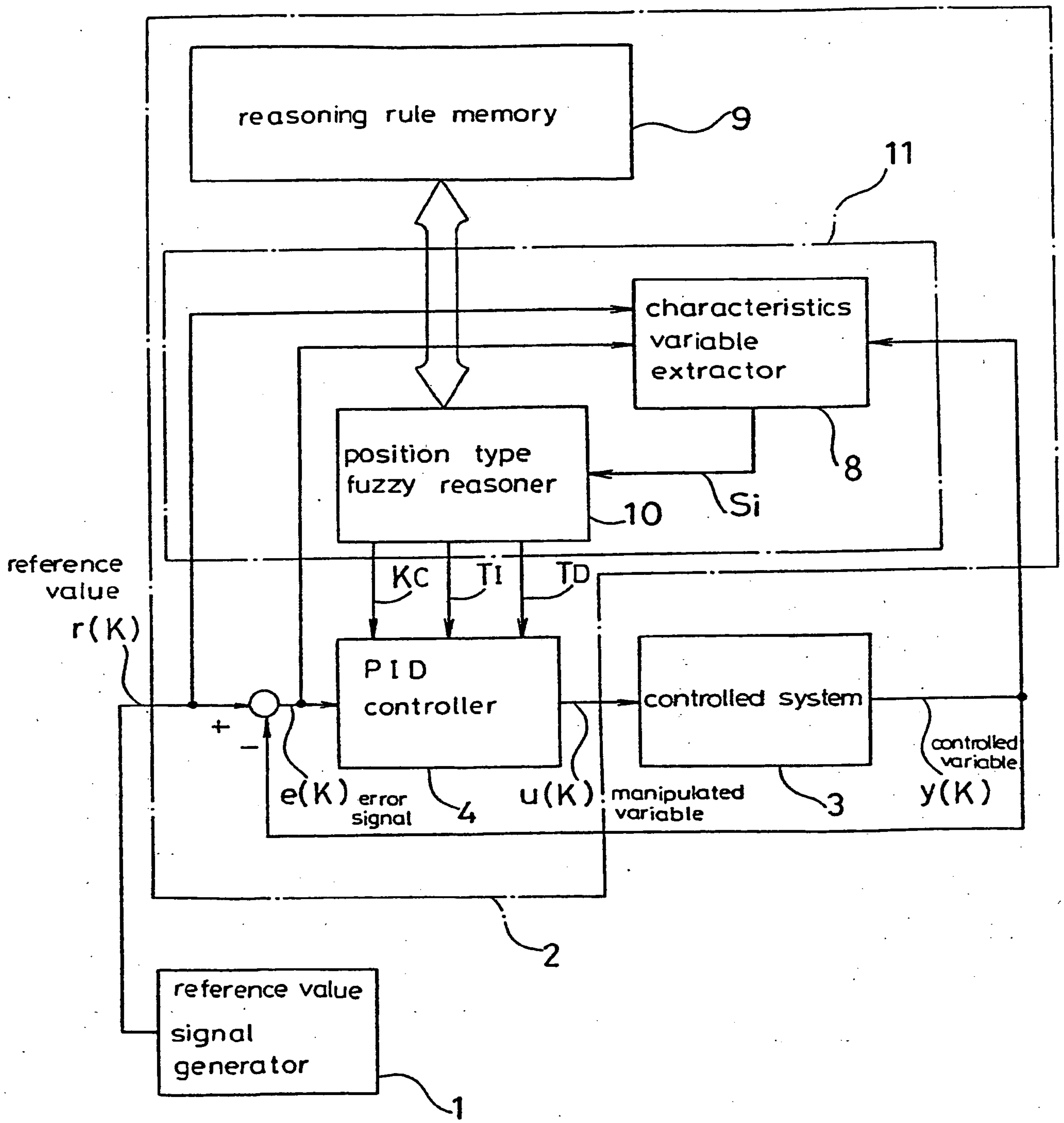
a reasoning rule memory for storing an reasoning rule to be used for reasoning a optimum control parameter of said controller;

a velocity type fuzzy reasoner which adjusts said control parameter in accordance with said reasoning rule from said characteristics variable; and

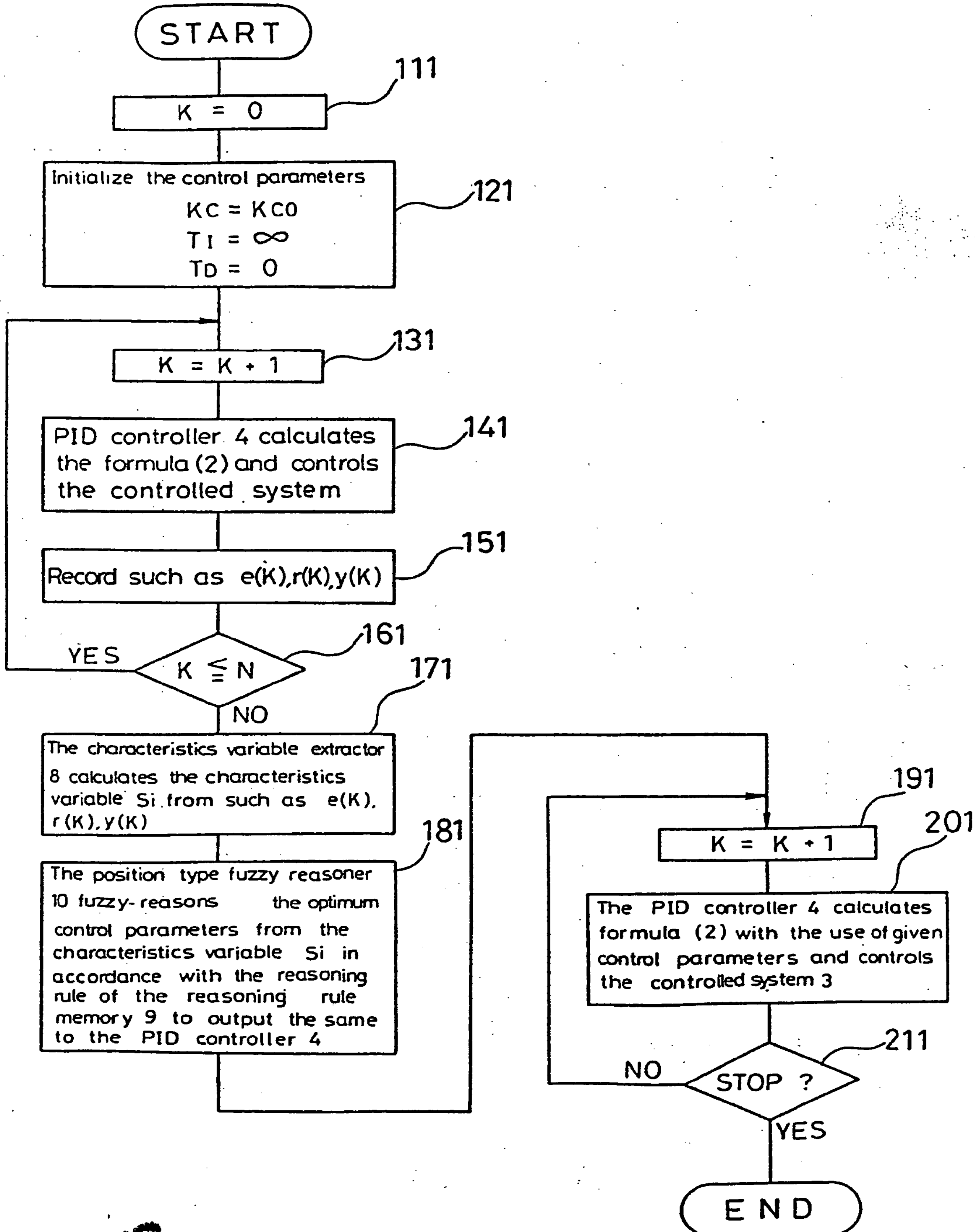
an integrator which integrates the output of said velocity type fuzzy reasoner and outputs the result to said controller.

14. An auto-tuning controller as defined in Claim 13, wherein said reasoning rule of velocity type fuzzy reasoning has a form comprising at least a former part proposition concerning a said characteristics variable the degree of coming into existence of which is represented by a predetermined membership function and a latter part proposition including an instruction concerning the adjustment of said control parameter.

F I G .1.


reasoning rule memory
9
11
characteristics variable extractor
position type fuzzy reasoner
8
Si
10
reference value
r(K)
Kc
TI
TD
PID controller
controlled system
+
−
e(K) error signal
4
u(K) manipulated variable
3
controlled variable
y(K)
2
reference value signal generator
1

F I G .2.


START
111
K = 0
121
Initialize the control parameters
KC = KC0
TI = ∞
TD = 0
131
K = K + 1
141
PID controller 4 calculates the formula (2) and controls the controlled system
151
Record such as e(K), r(K), y(K)
161
YES
K ≦ N
NO
171
The characteristics variable extractor 8 calculates the characteristics variable Si from such as e(K), r(K), y(K)
181
The position type fuzzy reasoner 10 fuzzy-reasons the optimum control parameters from the characteristics variable Si in accordance with the reasoning rule of the reasoning rule memory 9 to output the same to the PID controller 4
191
K = K + 1
201
The PID controller 4 calculates formula (2) with the use of given control parameters and controls the controlled system 3
211
NO
STOP ?
YES
END

F I G .3.

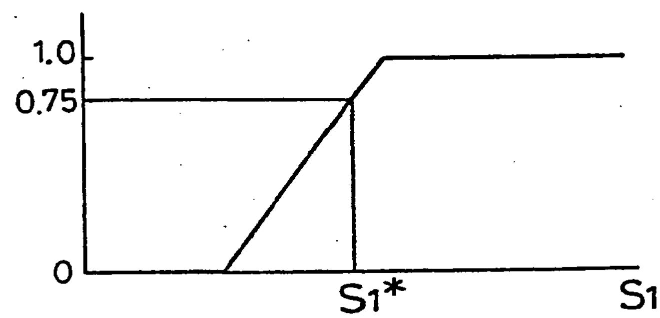
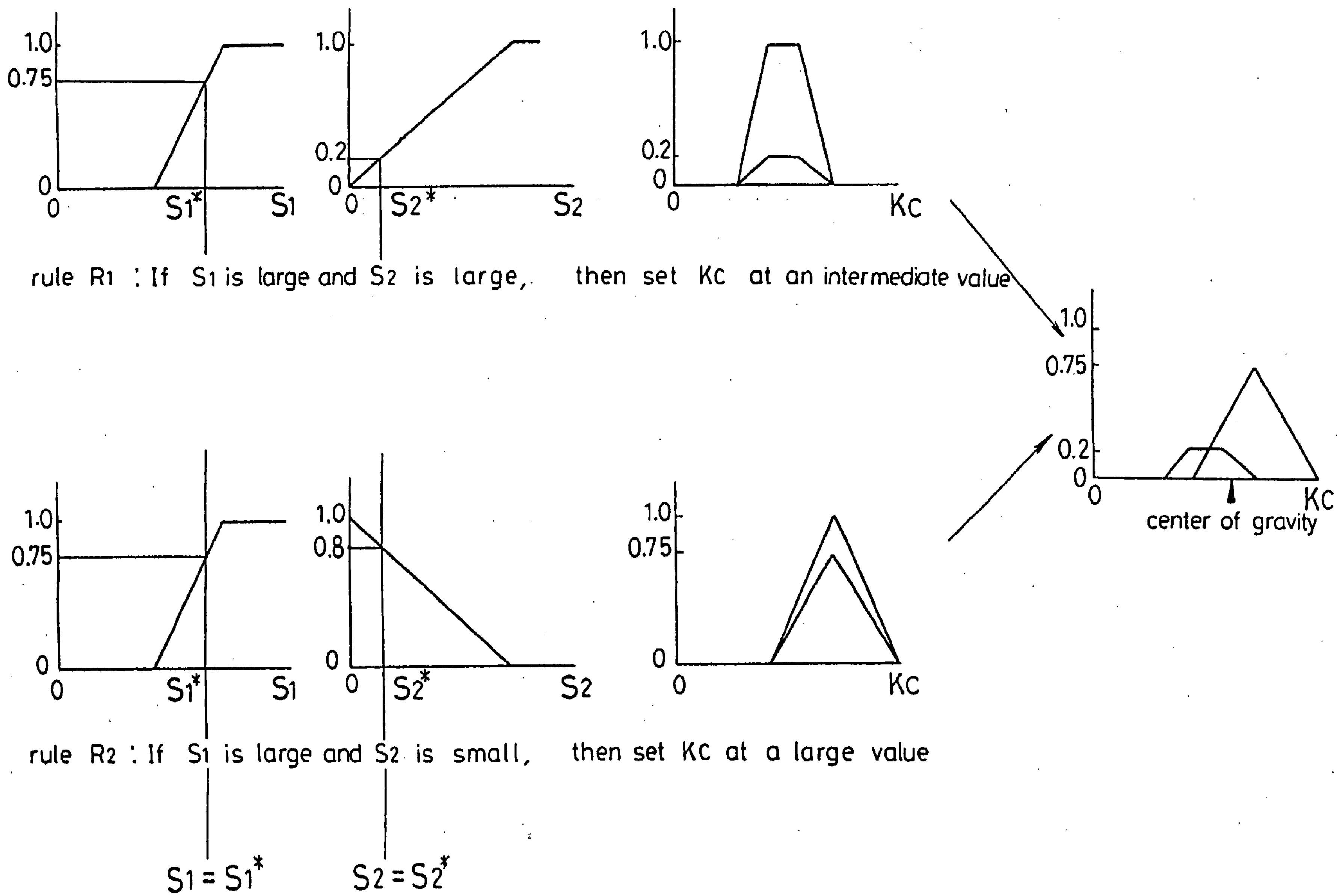
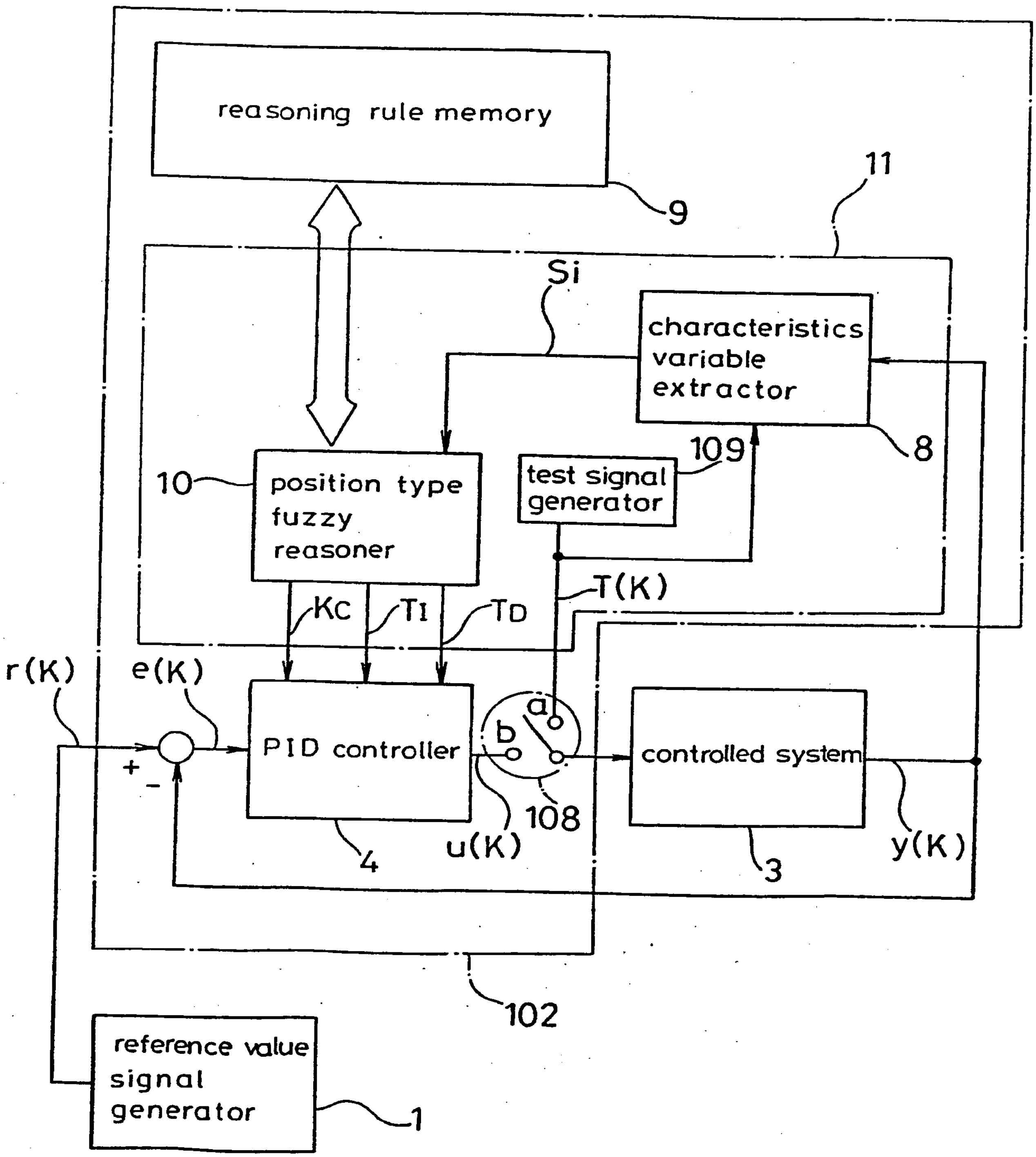


FIG. 4.



1.0
0.75
0
0
S1*
S1
1.0
0.2
0
0
S2*
S2
1.0
0.2
0
0
Kc
rule R1 : If S1 is large and S2 is large, then set Kc at an intermediate value
1.0
0.75
0
0
S1*
S1
1.0
0.8
0
0
S2*
S2
1.0
0.75
0
0
Kc
rule R2 : If S1 is large and S2 is small, then set Kc at a large value
S1 = S1*
S2 = S2*
1.0
0.75
0.2
0
0
Kc
center of gravity

F I G .5.


reasoning rule memory
9
11
Si
characteristics variable extractor
8
109
10
position type fuzzy reasoner
test signal generator
T(K)
Kc
TI
TD
r(K)
e(K)
PID controller
a
b
controlled system
+
-
108
u(K)
4
3
y(K)
102
reference value signal generator
1

F I G .6.

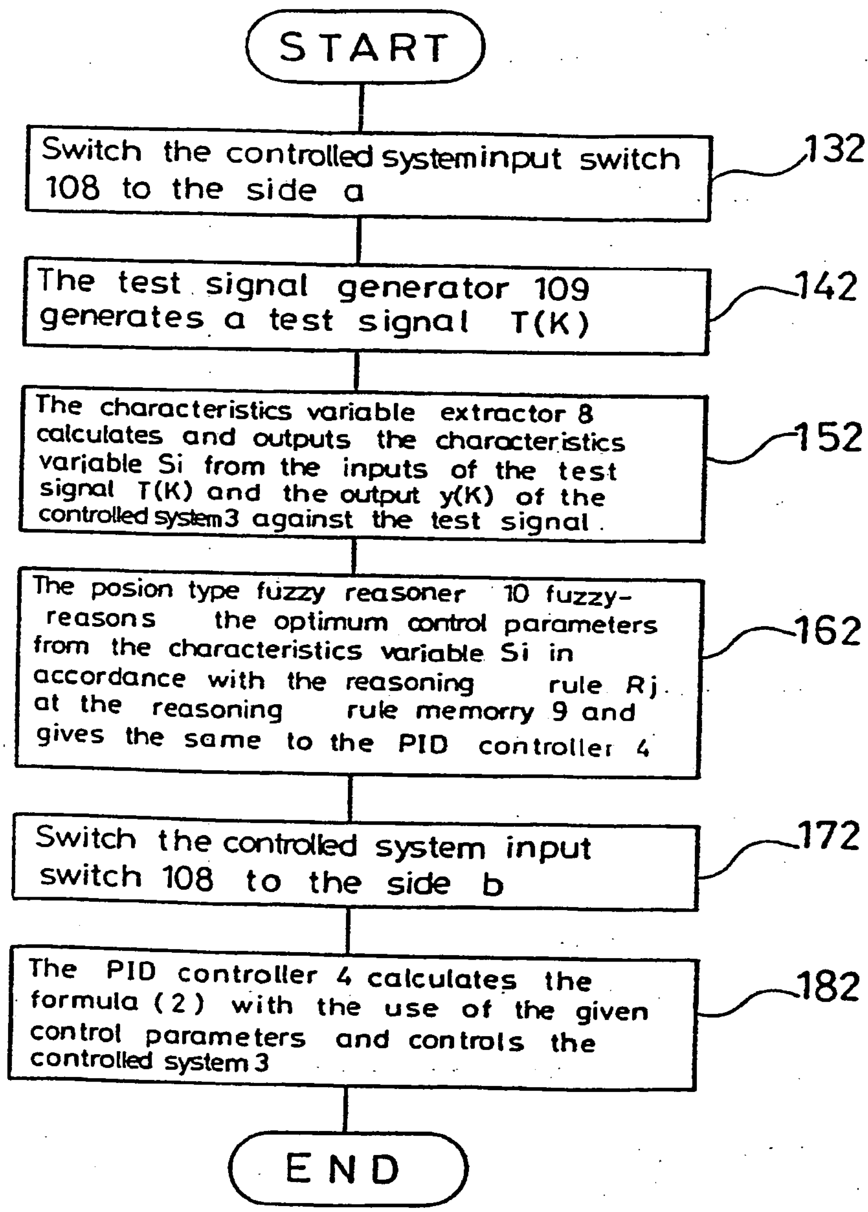
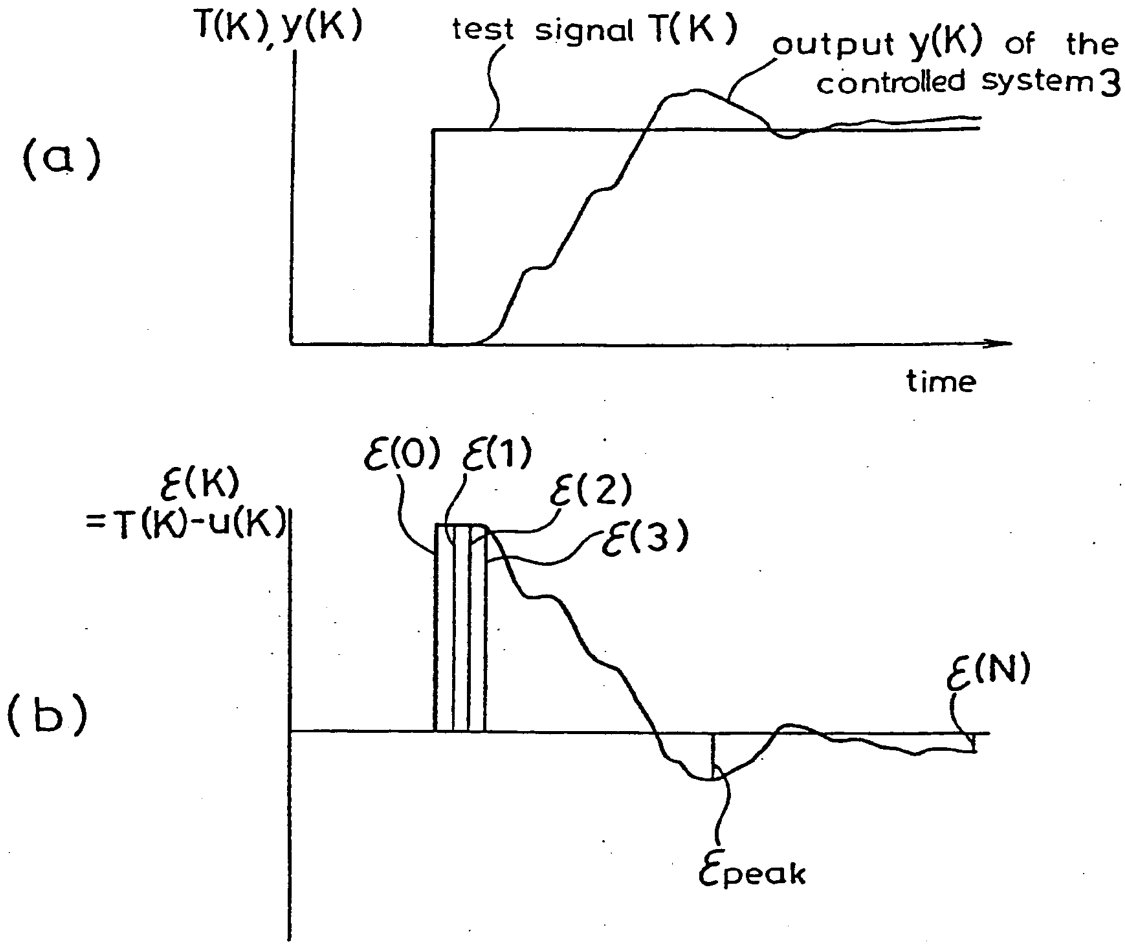

START
Switch the controlled systeminput switch 108 to the side a
132
The test signal generator 109 generates a test signal T(K)
142
The characteristics variable extractor 8 calculates and outputs the characteristics variable Si from the inputs of the test signal T(K) and the output y(K) of the controlled system3 against the test signal.
152
The posion type fuzzy reasoner 10 fuzzy-reasons the optimum control parameters from the characteristics variable Si in accordance with the reasoning rule Rj. at the reasoning rule memorry 9 and gives the same to the PID controller 4
162
Switch the controlled system input switch 108 to the side b
172
The PID controller 4 calculates the formula (2) with the use of the given control parameters and controls the controlled system 3
182
END

FIG .7.



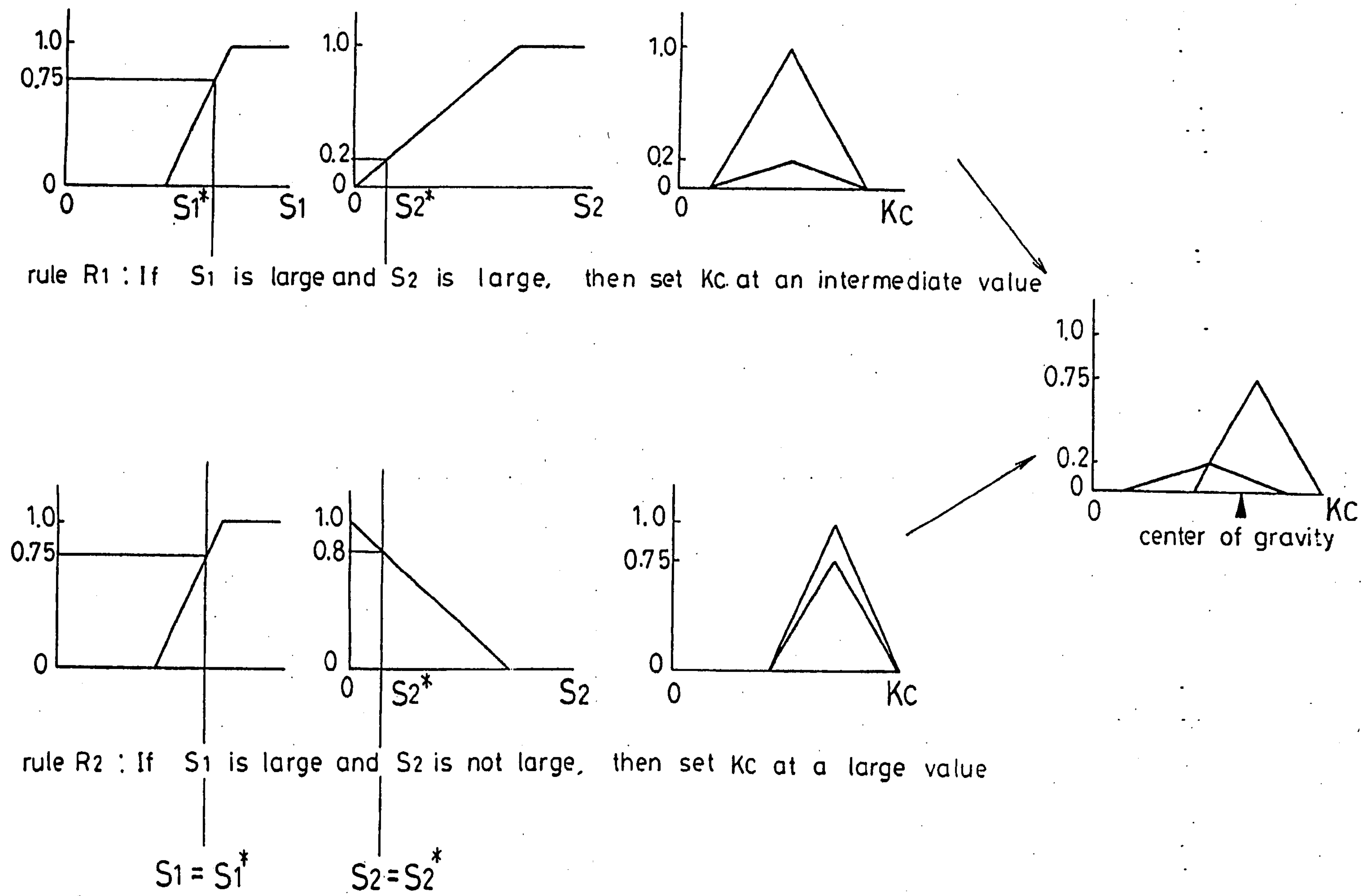
characteristics variable Si

$$S_1 = \frac{1}{N}\sum_{K=1}^{N} |\varepsilon(K)|$$

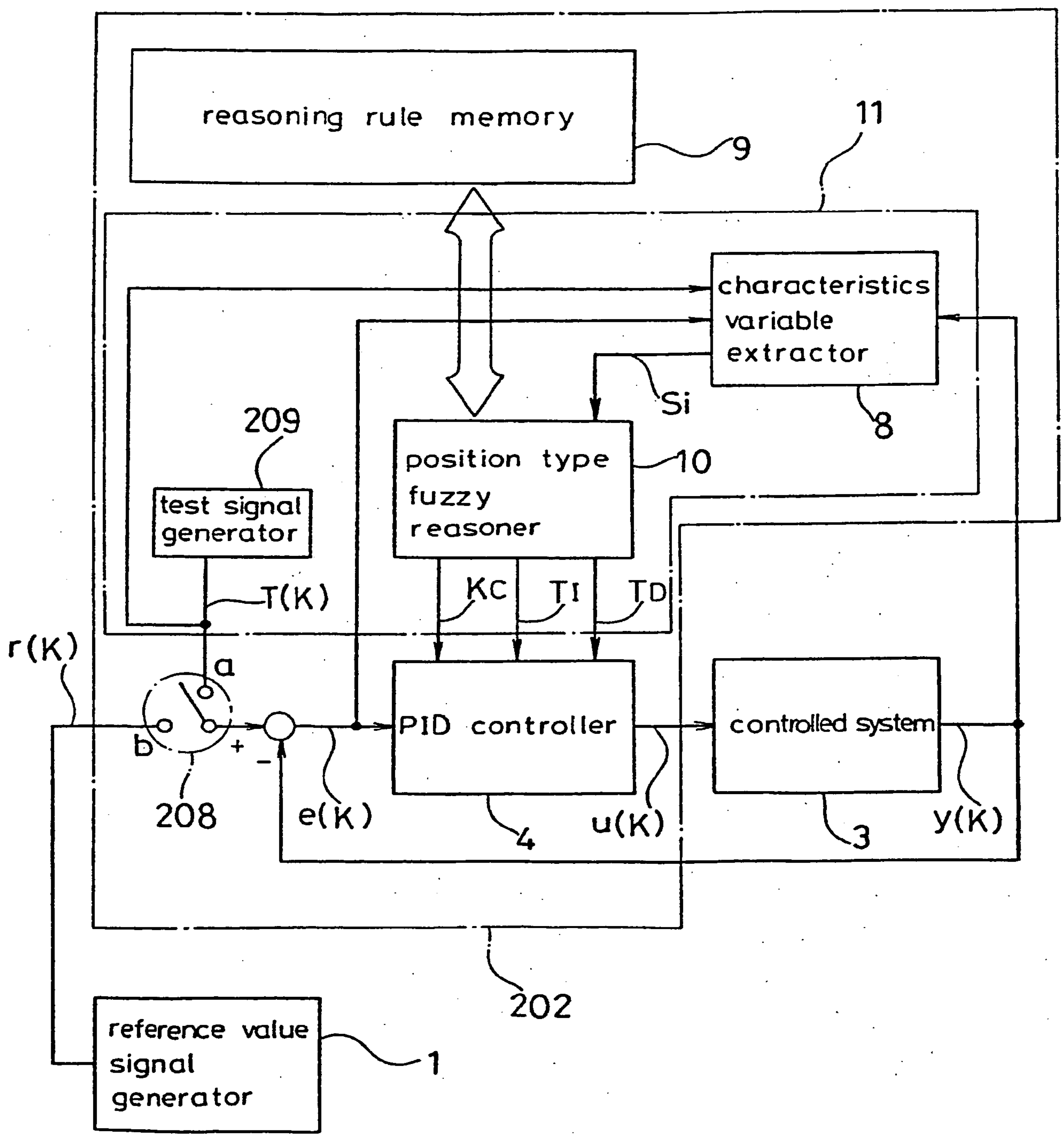
$$S_2 = -\frac{\varepsilon_{peak}}{\varepsilon(0)}$$

⋮

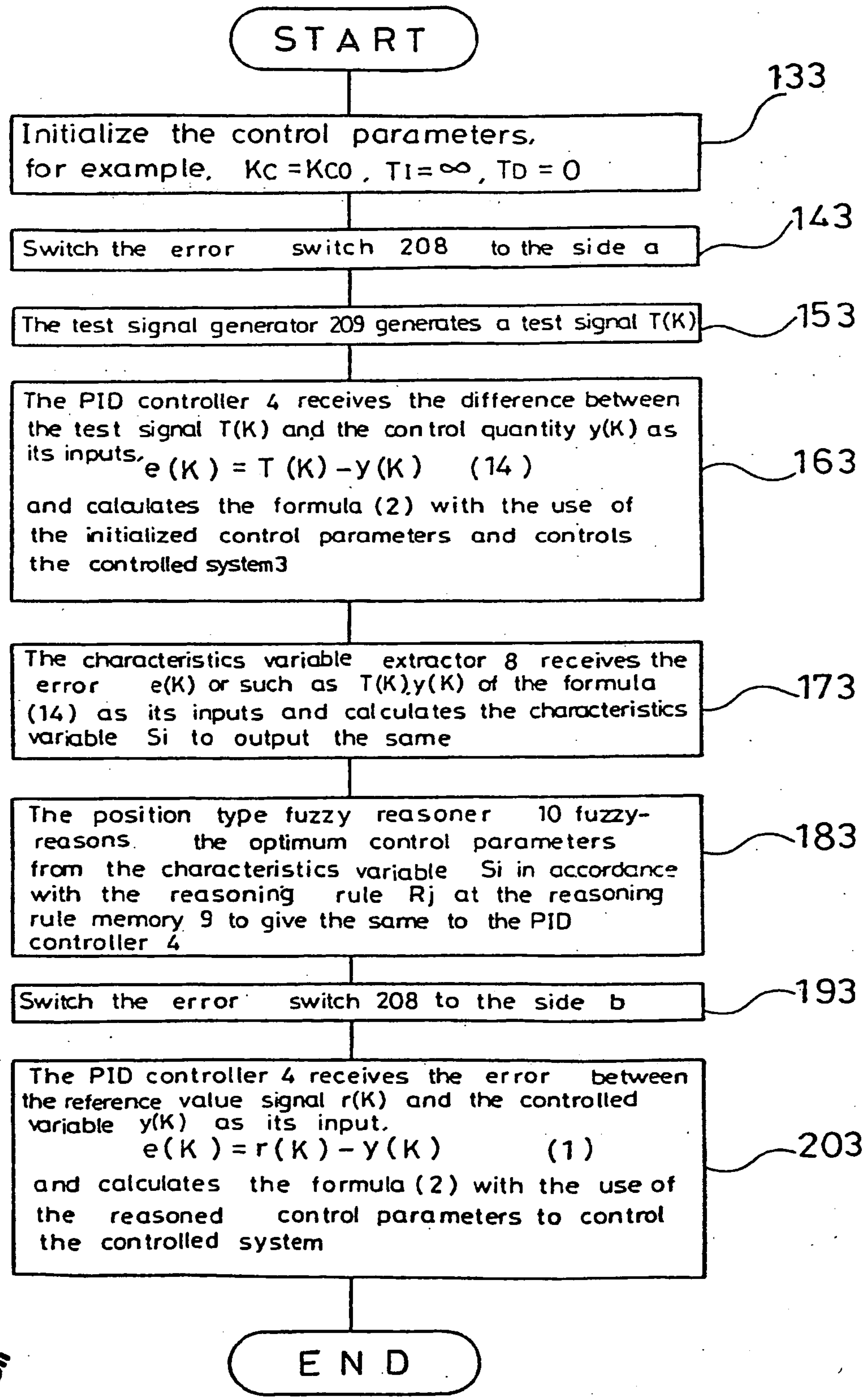
F I G .8.


1.0
0.75
0.2
0
S1*
S1
S2*
S2
Kc
rule R1 : If S1 is large and S2 is large, then set Kc at an intermediate value
0.8
rule R2 : If S1 is large and S2 is not large, then set Kc at a large value
S1 = S1*
S2 = S2*
center of gravity

F I G .9.

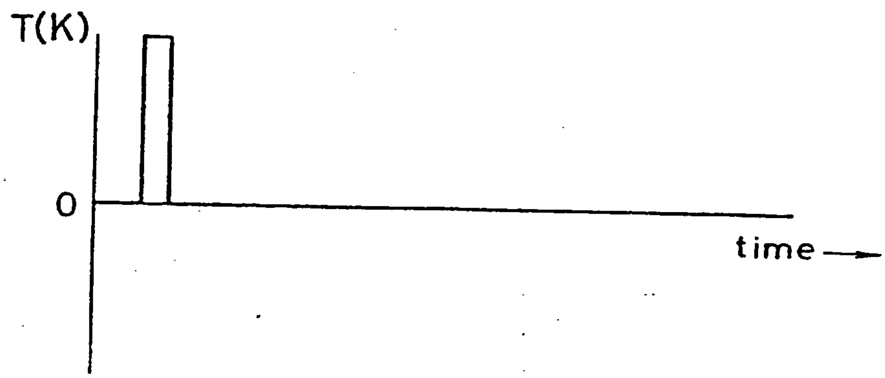

reasoning rule memory
9
11
characteristics variable extractor
Si
8
209
test signal generator
position type fuzzy reasoner
10
T(K)
KC
TI
TD
r(K)
a
b
+
−
PID controller
controlled system
208
e(K)
4
u(K)
3
y(K)
202
reference value signal generator
1

F I G .10.

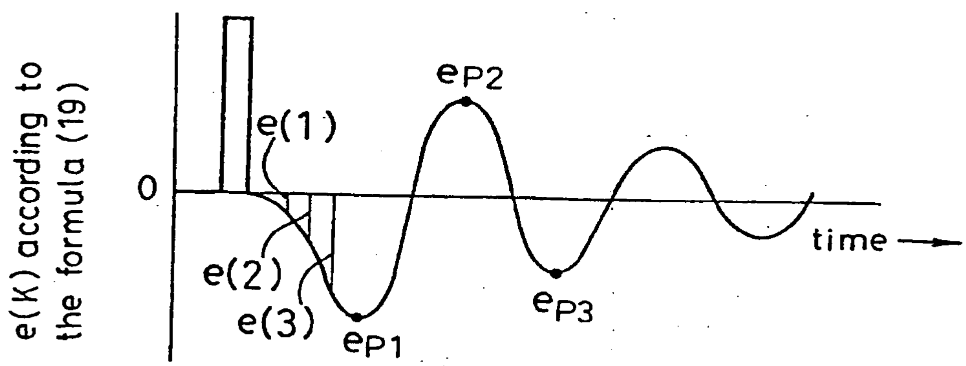

START
Initialize the control parameters, for example, $K_C = K_{C0}$, $T_I = \infty$, $T_D = 0$
133
Switch the error switch 208 to the side a
143
The test signal generator 209 generates a test signal T(K)
153
The PID controller 4 receives the difference between the test signal T(K) and the control quantity y(K) as its inputs, $e(K) = T(K) - y(K)$ (14) and calculates the formula (2) with the use of the initialized control parameters and controls the controlled system3
163
The characteristics variable extractor 8 receives the error e(K) or such as T(K),y(K) of the formula (14) as its inputs and calculates the characteristics variable Si to output the same
173
The position type fuzzy reasoner 10 fuzzy-reasons the optimum control parameters from the characteristics variable Si in accordance with the reasoning rule Rj at the reasoning rule memory 9 to give the same to the PID controller 4
183
Switch the error switch 208 to the side b
193
The PID controller 4 receives the error between the reference value signal r(K) and the controlled variable y(K) as its input, $e(K) = r(K) - y(K)$ (1) and calculates the formula (2) with the use of the reasoned control parameters to control the controlled system
203
END

F I G .11.

(a)



(b)

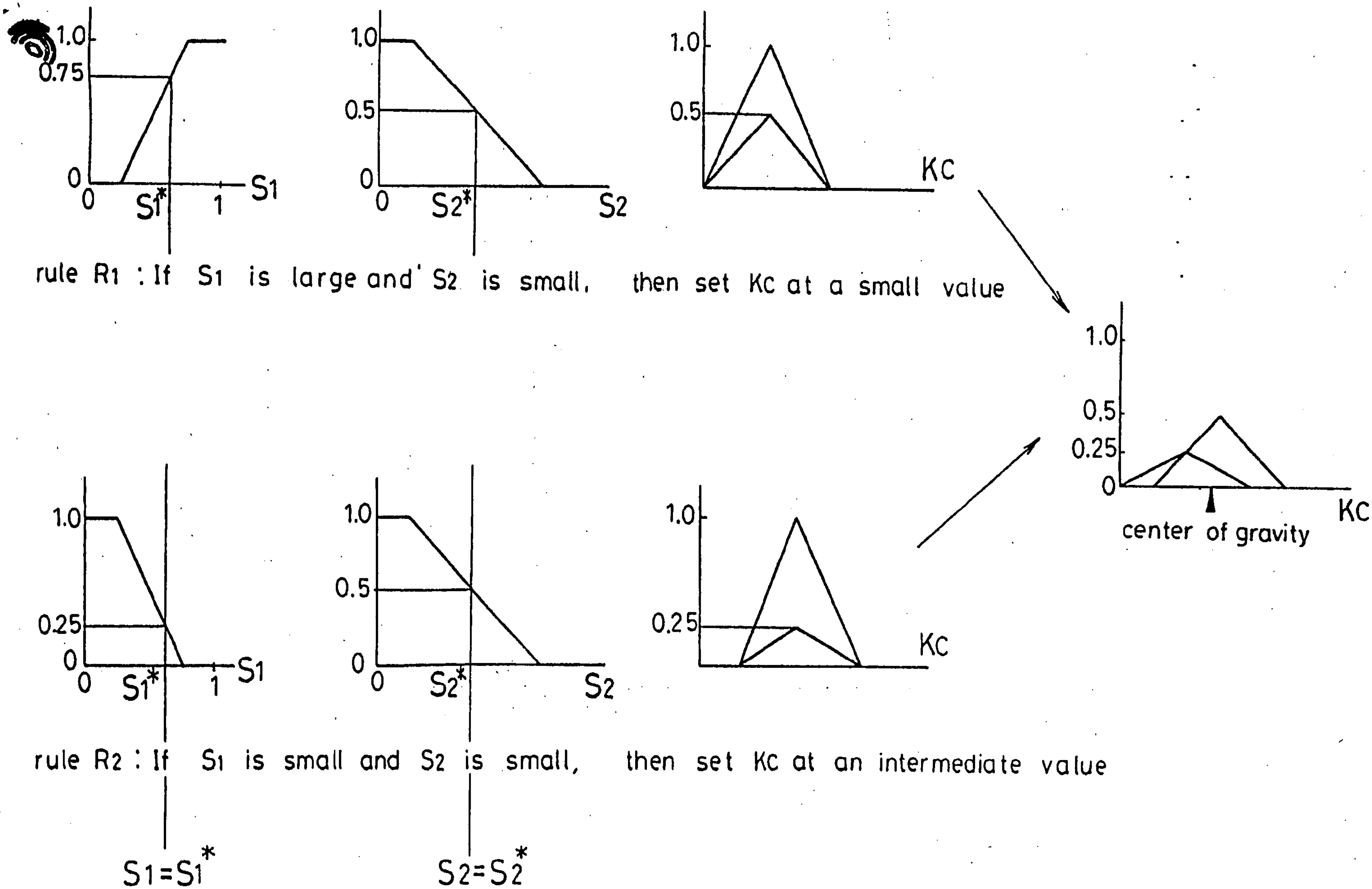


characteristics variable

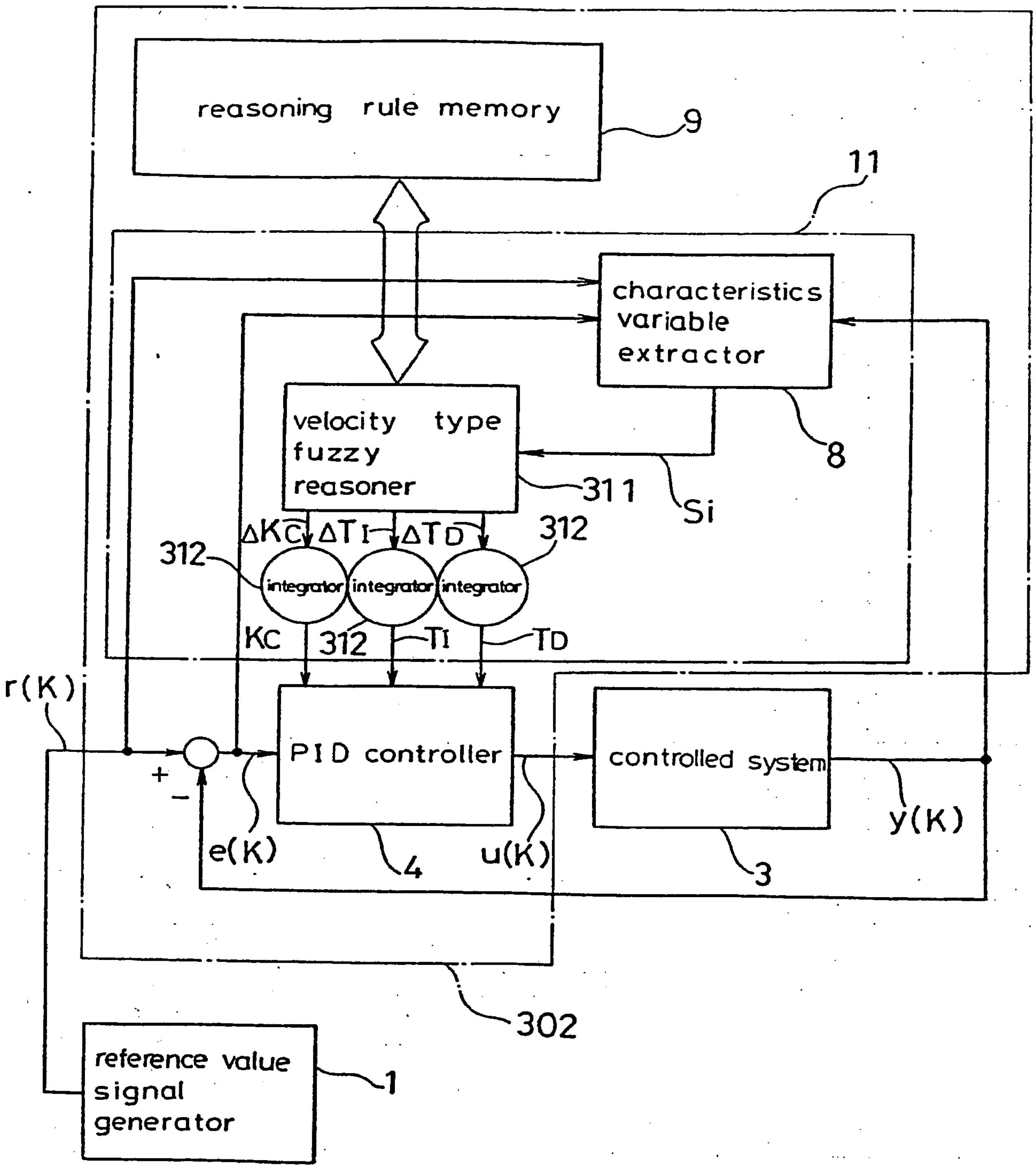
$$S_1 = -\frac{1}{2}\left(\frac{e_{P2}}{e_{P1}} + \frac{e_{P3}}{e_{P2}}\right)$$

$$S_2 = \frac{1}{N}\sum_{K=1}^{N}|e(K)|$$

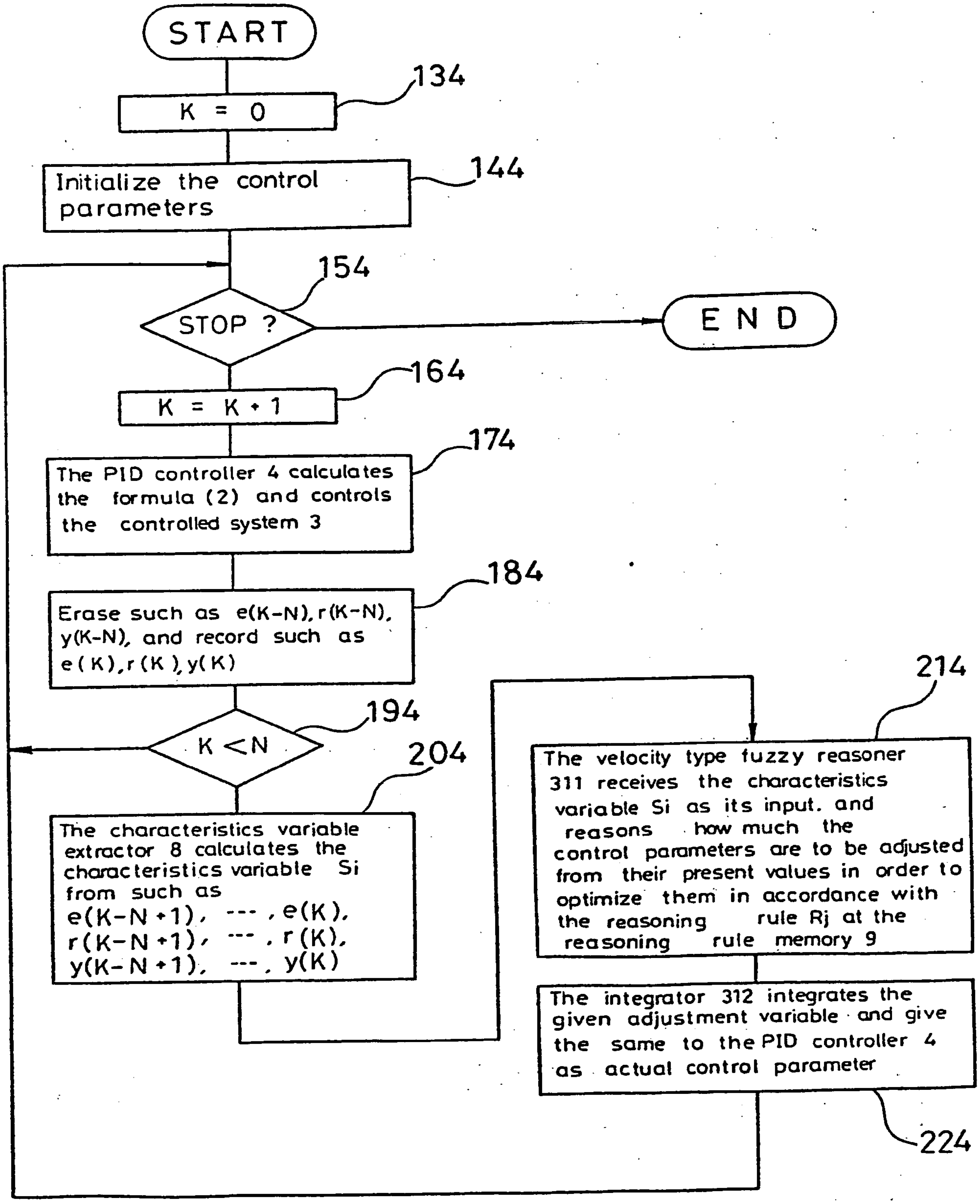
FIG.12.


1.0
0.75
0
0
S1*
1
S1
1.0
0.5
0
0
S2*
S2
1.0
0.5
Kc
rule R1 : If S1 is large and S2 is small, then set Kc at a small value
1.0
0.25
0
0
S1*
1
S1
1.0
0.5
0
0
S2*
S2
1.0
0.25
Kc
rule R2 : If S1 is small and S2 is small, then set Kc at an intermediate value
S1=S1*
S2=S2*
1.0
0.5
0.25
0
Kc
center of gravity

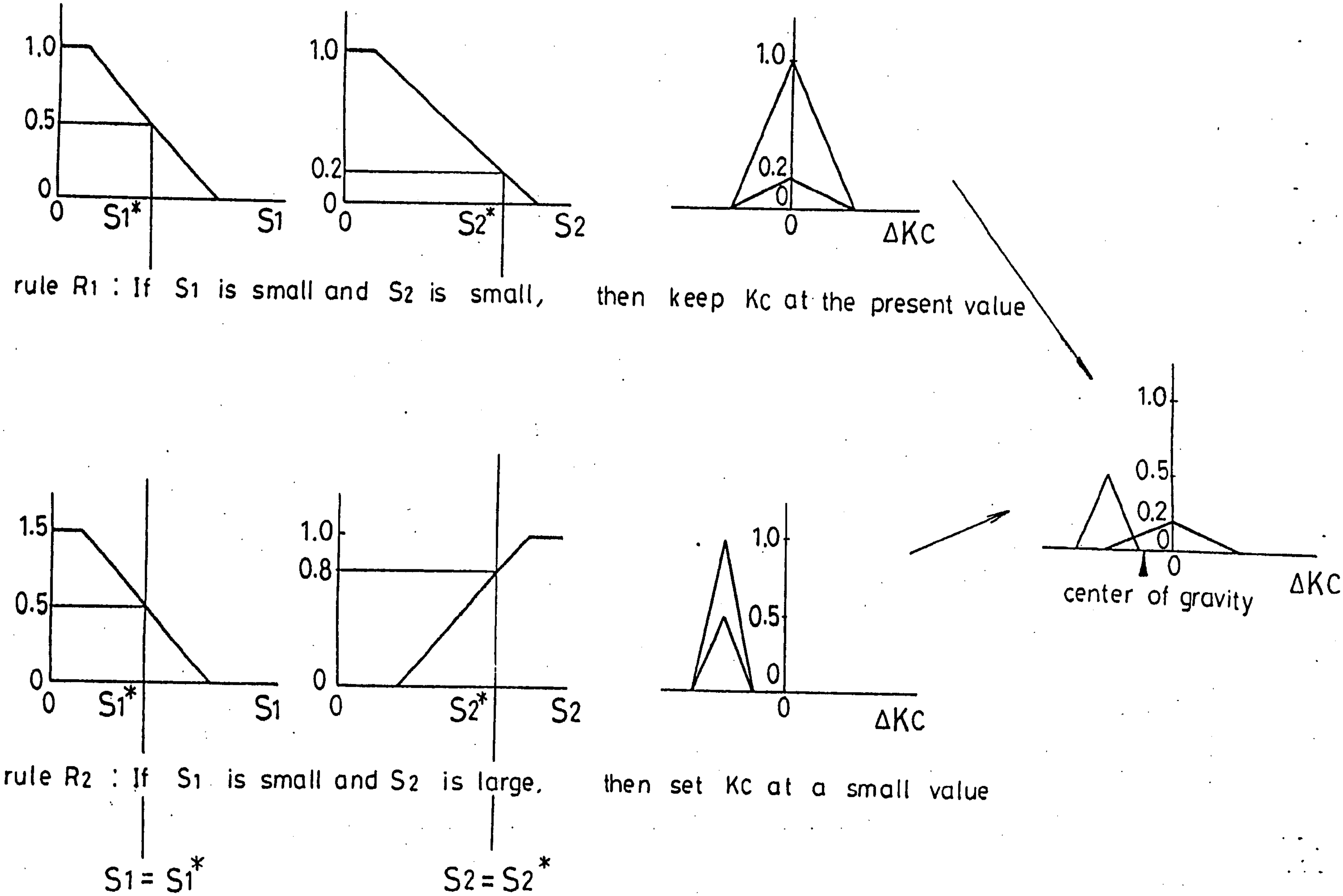
F I G .13.


reasoning rule memory
9
11
characteristics variable extractor
velocity type fuzzy reasoner
311
8
Si
ΔKC
ΔTI
ΔTD
312
312
integrator
integrator
integrator
KC
312
TI
TD
r(K)
+
−
PID controller
controlled system
y(K)
e(K)
4
u(K)
3
302
reference value signal generator
1

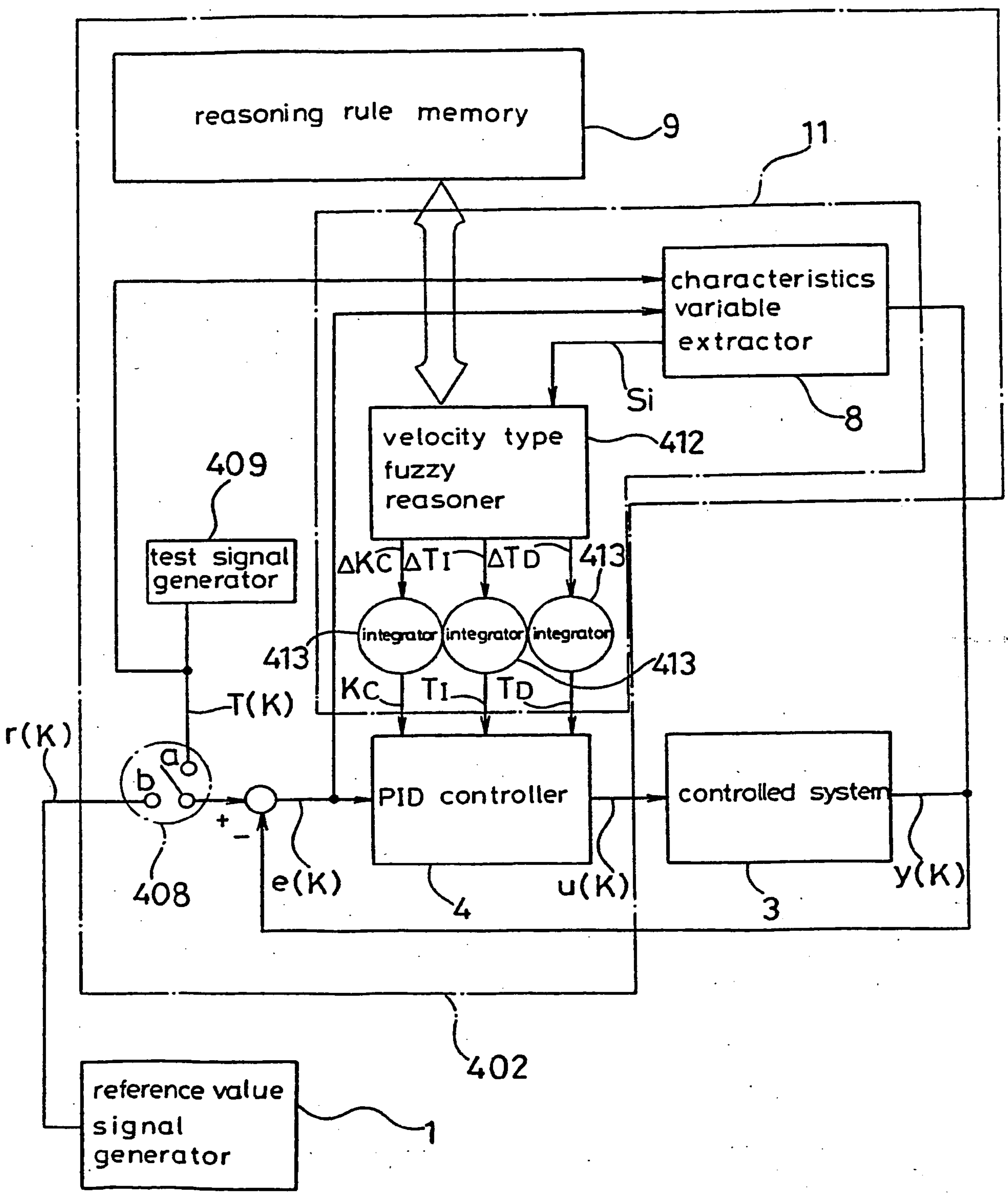
F I G 14.


START
K = 0
134
Initialize the control parameters
144
STOP ?
154
END
K = K + 1
164
The PID controller 4 calculates the formula (2) and controls the controlled system 3
174
Erase such as e(K-N), r(K-N), y(K-N), and record such as e(K), r(K), y(K)
184
K <N
194
The characteristics variable extractor 8 calculates the characteristics variable Si from such as e(K-N+1), ---, e(K), r(K-N+1), ---, r(K), y(K-N+1), ---, y(K)
204
The velocity type fuzzy reasoner 311 receives the characteristics variable Si as its input, and reasons how much the control parameters are to be adjusted from their present values in order to optimize them in accordance with the reasoning rule Rj at the reasoning rule memory 9
214
The integrator 312 integrates the given adjustment variable and give the same to the PID controller 4 as actual control parameter
224

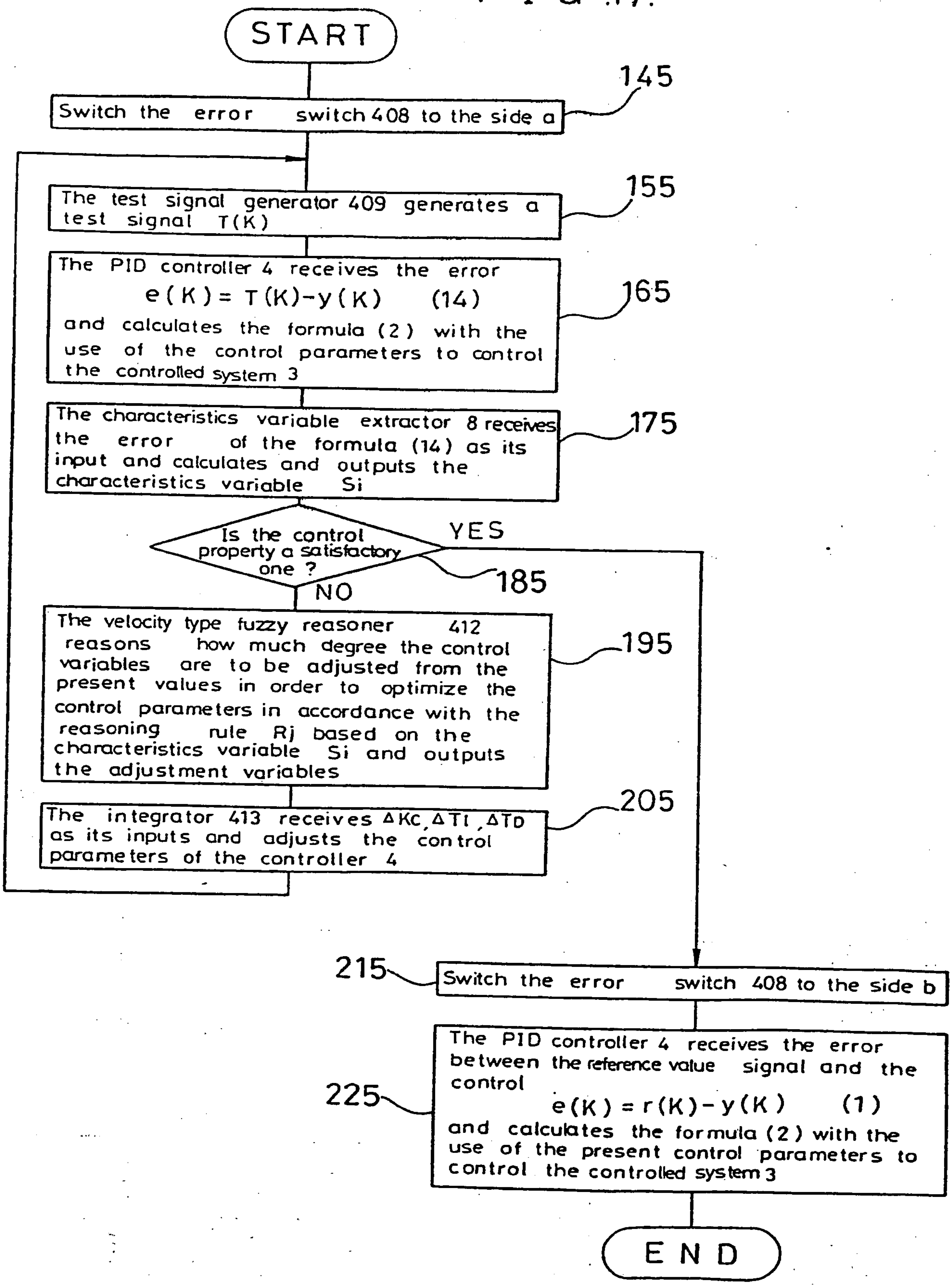
F I G .15.


1.0
0.5
0
0
S1*
S1
1.0
0.2
0
0
S2*
S2
1.0
0.2
0
0
ΔKC
rule R1 : If S1 is small and S2 is small, then keep Kc at the present value
1.5
0.5
0
0
S1*
S1
1.0
0.8
0
0
S2*
S2
1.0
0.5
0
0
ΔKC
rule R2 : If S1 is small and S2 is large, then set Kc at a small value
S1 = S1*
S2 = S2*
1.0
0.5
0.2
0
0
center of gravity
ΔKC

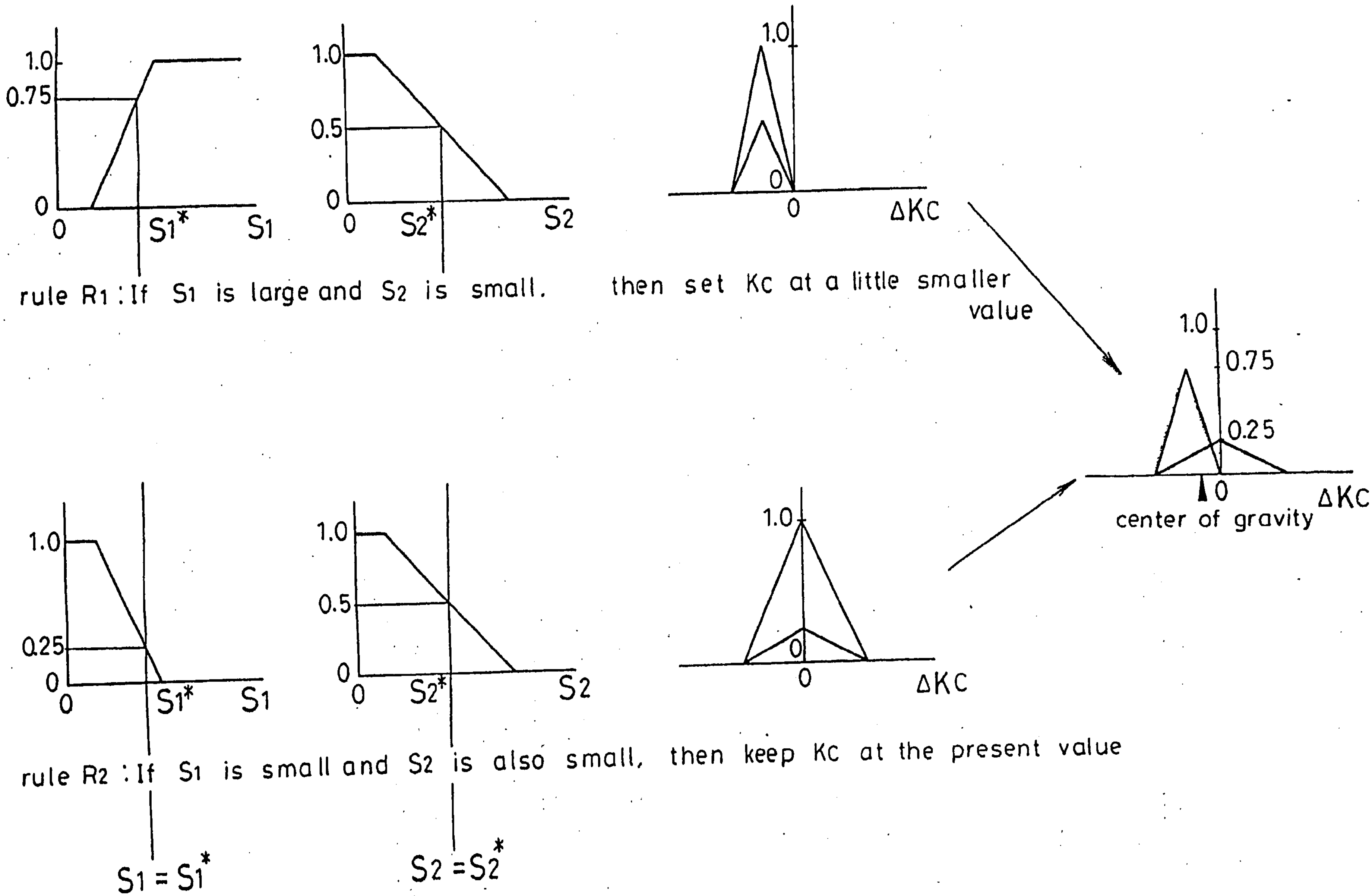
F I G .16.


reasoning rule memory
9
11
characteristics variable extractor
Si
8
velocity type fuzzy reasoner
412
409
test signal generator
ΔKC
ΔTI
ΔTD
413
integrator
integrator
integrator
413
413
KC
TI
TD
T(K)
r(K)
a
b
+
−
PID controller
controlled system
408
e(K)
4
u(K)
3
y(K)
402
reference value signal generator
1

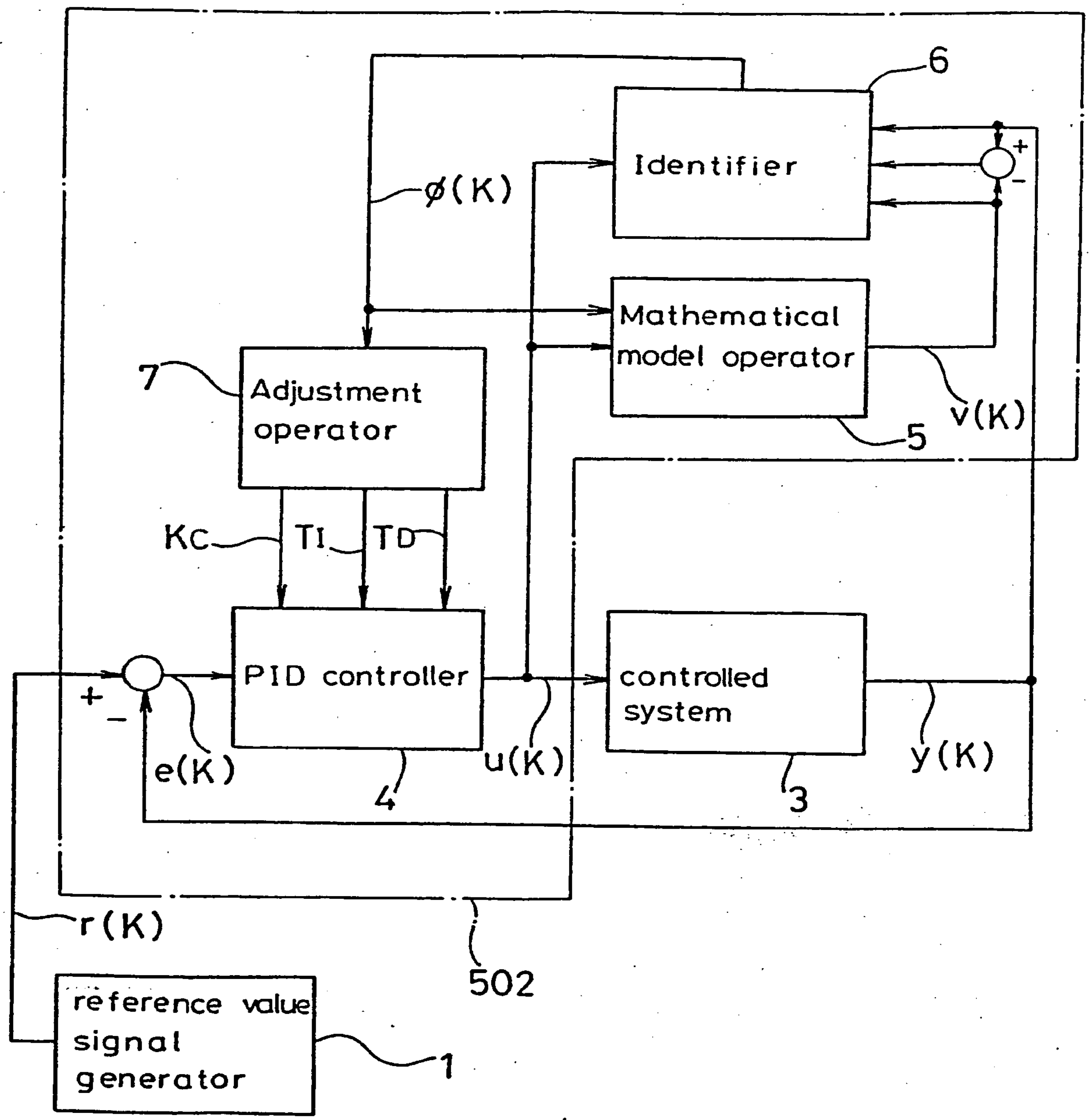
F I G .17.


START
145
Switch the error switch 408 to the side a
155
The test signal generator 409 generates a test signal T(K)
165
The PID controller 4 receives the error
e(K) = T(K)-y(K) (14)
and calculates the formula (2) with the use of the control parameters to control the controlled system 3
175
The characteristics variable extractor 8 receives the error of the formula (14) as its input and calculates and outputs the characteristics variable Si
Is the control property a satisfactory one ?
YES
185
NO
195
The velocity type fuzzy reasoner 412 reasons how much degree the control variables are to be adjusted from the present values in order to optimize the control parameters in accordance with the reasoning rule Rj based on the characteristics variable Si and outputs the adjustment variables
205
The integrator 413 receives ΔKC, ΔTI, ΔTD as its inputs and adjusts the control parameters of the controller 4
215
Switch the error switch 408 to the side b
225
The PID controller 4 receives the error between the reference value signal and the control
e(K) = r(K)-y(K) (1)
and calculates the formula (2) with the use of the present control parameters to control the controlled system 3
END

F I G . 18.


1.0
0.75
0
0
S_1^*
S_1
1.0
0.5
0
0
S_2^*
S_2
1.0
0
0
ΔKc
rule R1 : If S_1 is large and S_2 is small. then set Kc at a little smaller value
1.0
0.75
0.25
0
ΔKc
center of gravity
1.0
0.25
0
0
S_1^*
S_1
1.0
0.5
0
0
S_2^*
S_2
1.0
0
0
ΔKc
rule R2 : If S_1 is small and S_2 is also small, then keep Kc at the present value
$S_1 = S_1^*$
$S_2 = S_2^*$

F I G .19. (PRIOR ART)



0241286

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87 30 3089

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	PROCEEDINGS OF THE 24TH IEEE CONFERENCE ON DECISION & CONTROL, IEEE CONTROL SYSTEMS SOCIETY, 11th-13th December 1985, Fort Lauderdale, Florida, vol. 1, pages 602-608, IEEE; H.R. VAN NAUTA LEMKE et al.: "Fuzzy pid supervisor" * Page 604, "The fuzzy supervisor of the PID controller"; figures 3,4 * ---	1,4	G 05 B 13/02
A	MEASUREMENT AND CONTROL, vol. 17, no. 11, December 1984/January 1985, pages 409-413, Dorking, GB; B. KNIGHT et al.: "The use of expert systems in industrial control" * Whole document * ---	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
D,A	ISA TRANSACTIONS, vol. 20, no. 2, February 1981, pages 3-10, ISA; A.B. CORRIPIO et al.: "Industrial application of a self-tuning feedback control algorithm" ---		G 05 B
A	IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS, vol. SMC-15, no. 1, January/February 1985, pages 175-189, IEEE; J. MAIERS et al.: "Applications of fuzzy set theory" -----		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	01-07-1987	KOLBE W.H.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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E : earlier pat nt document, but published on, or aft r th filing date
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